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STABILITY OF THE LONG-TERM FLY ASH MOUND AT THE NANTICOKE TGS LAGOON

Report No 89-95-K

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ABSTRACT

The stability of four slope sections of the proposed long-term fly ash disposal mound at the Nanticoke TGS site was analyzed. The phreatic surface location used in this study was calculated by the analytical model developed in a previous study. It has been found that the factor of safety of the slope is very sensitive to the location of the phreatic surface used in the analysis. Results of this study indicate that no major slope failure is anticipated.

A parametric study on the effect of the phreatic surface location within the ash mound and of the shear strength of the ash on the stability of the slopes was carried out. The results of this parametric study have provided a better understanding of the factors controlling the stability of the long-term fly ash mound at the Nanticoke site.

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STABILITY OF THE LONG-TERM FLY ASH MOUND AT THE NANTICOKE TGS LAGOON

INTRODUCTION

In May 1986, the stability of the slopes of the proposed fly ash mound at the Nanticoke ash lagoon storage area was evaluated by using the simplified Bishop's circular arc method /1,2/. Owing to the lack of groundwater pressure data within the proposed ash mound, an assumed phreatic surface (water table) within the proposed ash mound was used for the analysis. The results of the study indicated the need to improve the stability of the slopes of the proposed fly ash mound.

Various means for improving the stability of the slopes were considered. The results of a slope stability analysis performed in June 1986 indicated that the safety factor of the slopes could be improved to an acceptable level by either installing a blanket drain at the toe of the slopes or flattening the slopes /3/.

Because of the cohesionless and light weight nature of fly ash (specific gravity = 2.4), the stability of the slopes of the ash mound constructed of this type of material is sensitive to the variation in groundwater pressure within the slope. Thus in 1988, a study was undertaken on the groundwater build-up from the proposed fly ash mound due to the downward seepage of the excess water from the placement of the very wet ash and the infiltration from precipitation/4/. An analytical model for the prediction of the location of the phreatic surface with time within a continuous stacking ash mound was developed. The model was then used to predict the phreatic surface location within the proposed ash mound at the Nanticoke site.

The predicted phreatic surface location within the proposed ash mound at the Nanticoke site is lower than the phreatic surface assumed in the initial slope stability analyses. Thus in this study, the location of the phreatic surface predicted by the analytical model was used to re-evaluate the stability of the slope of the proposed ash mound. In addition, a parametric study was performed to evaluate the sensitivity of the calculated safety factor of the slopes to the variation in the phreatic surface location within the slopes and variation in the shear strength parameters of the ash.

REVIEW OF PREVIOUS WORKS

Slope stability analyses were performed on three selected critical cross-sections of the proposed ash mound at the Nanticoke ash lagoon storage area as requested by the Civil Design Department. Figure 1 shows the locations of these cross-sections. It should be pointed out that Figure 1 shows only the final design of the proposed mound ("long-term" condition). The plan view of the mound during the construction phase is changing all the time and is not shown in Figure 1. In Figure 2, the cross-section, ash properties used and the assumed phreatic surface location of section S1 "left side" are presented. This cross-section represents a "long-term" critical section of the mound. In Figures 3 and 4, section S1 "right side" and section S3 are presented respectively. These two cross-sections represent the critical "short-term" (during construction) cross-sections of the proposed mound*. The unit weight of the upper and lower ash, determined by laboratory tests, was 95 and 90 pcf, respectively. The shear strength of the ash was determined by a back calculation of a dyke failure which occurred in July 1985 along the edge of the south secondary settling cell. The results of the calculation indicated that the upper and lower ash have friction angles of 35 and 28 degrees respectively. In this study a friction angle of 30 degrees was assigned to the lower ash because there will be a thicker overlying ash layer over the lower ash in the long-term ash mound. The overlying ash will consolidate the lower ash and increase its strength. The results of the analysis are summarized as follows:

Section	S1 "left side"	S1 "right side" (short-term)	S3 (short-term)
Safety Factor	1.08	0.91	1.47

The results obtained in 1986 indicated that section S1 "left side" had a marginal safety factor and section S1 "right side" (short-term) was unsafe. Subsequently, various slope stability improvement methods were studied to increase the stability of these slopes. The results of the study indicated that section S3 (short-term) is very stable and no slope stability improvement is required. Thus, in the subsequent study, the section S3 "long-term" condition (cross section at the end of construction, Figure 5) is analyzed instead. In addition to the three critical sections selected, section S4, which is shown in Figure 6, was also included in the study.

The shear strength and material properties of the ash used in this analysis were identical to those values used in the initial study. The slope stability improvement methods used were slope flattening and the installing of blanket drains. A summary of the results obtained in 1986 is as follows:

*the geometry of all sections is from the final design of the ash mound except those labelled "short-term" (ie during construction)

Section	S1 "left side"	S1 "right side" (short-term)	S3	S4
Original F.S (Initial study)	1.08 (Fig.2)	0.91 (Fig.3)	1.07 (Fig.5)	1.0 (Fig.6)
F.S improvement - blanket drain	1.14 (Fig.7)	----	1.47 (Fig.8)	1.20 (Fig.9)
F.S improvement - slope flattening	1.18 (flatten slope from 3:1 to 4:1 Fig.10)	1.26 (from 2:1 to 3:1, Fig.11)	----	----
F.S improvement - both slope flattening and blanket drain	1.48 (flatten slope from 3:1 to 4:1 fig.12)	1.57 (from 2:1 to 3:1, Fig.13)	----	----

The results of this study indicated that both slope flattening and the use of a blanket drain are effective means for improving the stability of the slopes of the proposed ash mound. Blanket drains are preferred to the slope flattening method, because slope flattening will reduce the fly ash storage capacity of the mound tremendously.

SLOPE STABILITY BASED ON PREDICTED PHREATIC SURFACE LOCATIONS

The section S1 "right side" (short-term) was not included in the 1988 analysis in view of the present ash stacking procedure adopted at the site (Figure 14). This procedure consists of initially stacking wet ash in the mound. Sufficient time is provided for the water within the wet ash to drain out by gravity flow. The resulting dryer ash (with a moisture content of 20 to 25 %) was then excavated and used to construct access roads beside the excavation. Thus the phreatic surface (if it exists) within the "short-term" slope section such as S1 "right side" (short-term) should be very low and no stability problem is anticipated.

The location of the calculated phreatic surfaces* within section S1 "left side", S3 and S4 are shown in Figures 15, 16 and 17 respectively. The shear strength and unit weight of the ash are also listed in the figures. The resulting factor of safety and the percentage improvement in the factor of safety caused by the difference in the assumed phreatic surface elevation used in the initial stability analysis and the phreatic surface elevation predicted by the analytical model are listed below.

* Refer to Appendix "A" for details of calculations.

Section	S1 "left side" Initial	S1 "left side" Present	S3 Initial	S3 Present	S4 Initial	S4 Present
Phreatic surface elevation	696′ (212.1m)	667′ (203.3m)	696′ (212.1m)	667′ (203.3m)	696′ (212.1m)	667′ (203.3m)
Safety Factor	1.08	1.52	1.07	1.28	1.00	1.27
Increase in F.S	47.3 %		19.7 %		27.3 %	

Significant differences in the calculated safety factors of the slopes, based on the two different phreatic surface elevations, were obtained.

PARAMETRIC STUDY

The results shown in the last section indicated that the phreatic surface locations (groundwater pressure) within an ash mound has a significant effect on the stability of the mound. As the analytical model developed for the prediction of the phreatic surface elevation within the ash mound has only been calibrated with limited groundwater pressure measurements from the field, it would be judicious to investigate the sensitivity of the calculated safety factor of the ash mound due to the variations in phreatic surface elevations.

The results of a field investigation performed in a previous study at the Nanticoke lagoon site indicated large variations in the consistency of the ash within the site/5/. Thus the uncertainty involved in the stability of the slopes of the ash mound due to the variation in shear strength value of the ash was also investigated in this section. The range of the parameters studied are:

	Original Values	Variation from Original Values
Phreatic Surface Elevation	667′ (203.3m)	+/- 10′ (3.05 m)
Friction Angle Upper ash	35 degree	+/- 5 degree
Friction Angle Lower ash	30 degree	+/- 5 degree

In addition, section S2 (Figure 18) which is a modification of the section S1 "left side" was included in this parametric study. Section S2 has a slope inclination of 4:1 whereas section S1 "left side" has a slope of 3:1. The selection of this cross-section is to study the effect of slope inclinations on the stability of the slopes.

RESULTS OF PARAMETRIC STUDY

The results of the parametric study for each slope cross-section are summarized as follows:

Section S1 "Left Side"

The effect of the changes in phreatic surface elevations on the calculated factor of safety of the slope is shown in Figure 19. This figure indicates that with the change in the phreatic surface elevation by 10 feet (3.05m), the corresponding average change in the calculated safety factor of the slope is 8%.

The effect of the variation in shear strength parameters(the friction angle) of the ash on the calculated safety factor is shown in Figures 20 and 21 respectively. These figures indicate that the calculated safety factor is much more sensitive to the variation in shear strength of the lower ash than the upper ash.

Section S2

The effect of the changes in the phreatic surface elevation on the calculated safety factor of this section is plotted in Figure 22. The average percentage change in the calculated safety factor due to the change in phreatic surface elevation by 10 feet (3.05m) is 9%.

The variation in calculated safety factor with the change in shear strength (friction angle) of the upper and lower ash is plotted in Figures 23 and 24. The variation in shear strength of the lower ash has a more predominant effect on the calculated safety factor of the slope.

Section S3

The effect of change in the phreatic surface elevation on the calculated safety factors of this cross-section is marginal (Figure 25) and has an average value of 3%.

The variation in the shear strength of the upper ash has a minimum effect on the calculated safety factor (Figure 26). The average change in the calculated safety factor due to the variation in the shear strength of the lower ash is about 20% (Figure 27). This result is due to the limited area of the critical slip surface that passed through the upper ash.

Section S4

In Figure 28, the effect of the change in the phreatic surface elevation on the calculated safety factor of the slope is plotted. The variation in the phreatic surface elevation has a rather significant effect on the calculated safety factor (14.5%).

In this case, the change in the shear strength of the lower ash has a significant effect on the calculated change in the safety factor of the slope (Figure 29). The variation in shear strength of the upper ash has no effect on

the calculated safety factor (Figure 30). The critical slip surface shown in Figure 16 clearly indicates that the surface passes only through the lower ash.

DISCUSSION AND CONCLUSIONS

In this study, the stability of four slope sections of the proposed fly ash disposal mound at the Nanticoke site were analyzed. The phreatic surface elevation used in this study was calculated by the analytical model developed in a previous study/5/.

The safety factors of the slopes based on the calculated phreatic surface elevations are much higher than the safety factors of the slopes based on the assumed phreatic surface elevation used in the initial analysis. In view of the sensitivity of the calculated safety factor of the slopes to the variations in phreatic surface elevations and consistency of the ash (Figures 28 and 29), a parametric study which consisted of four slope sections was calculated. From the results of this study the following conclusions were drawn:

1. For the four slope sections analyzed, the effect of the change in the phreatic surface elevations on the stability of the slopes is plotted in Figure 31. This figure clearly shows that the safety factor of the slopes is sensitive to the change in the phreatic surface elevations. For section S4, with an increase in the calculated phreatic surface elevation by 10 feet (3.05m), a marginal factor of safety (F.S=1.08) was calculated. Thus further calibration of the analytical model for the prediction of the phreatic surface elevation within the ash mound should be carried out on a regular basis. The groundwater pressure measurements from the field should be used to ensure the stability of the slopes of the ash mound.

2. The variation in the shear strength values of the upper ash has a minimum effect on the stability of the slopes. This is due to the minimum area of the critical slip surface that passed through the upper ash (Figure 32).

3. The effect of the variation in the shear strength of the lower ash has a significant effect on the safety factor (Figure 33) of the slopes. This finding indicates that in areas where a soft ash zone existed, local slope failure may occur.

4. The failure zone thickness versus the slope inclination of the slopes studied are plotted in Figure 34. This figure indicated that in general the thickness of the failure zone is about 10 ft to 15 ft (3.05m to 4.5m) and the steeper the slope, the thinner is the failure zone. This implied that in areas where steep slopes existed, sloughing type failures may occur.

The results of this study indicated that the stability of the slopes with the calculated phreatic surface is safe. However, with the special variation in consistency of the ash and the uncertainty involved in the calculated phreatic surface location, the stability of the slopes should be ensured by monitoring the pore water pressures within the ash mound. In addition, because of the extensive height of the mound and the large catchment area existing at the top

of the mound, erosion of the slope surface by surface run-off and wind may be critical. It is therefore recommended that the slope surface be protected by vegetation. Interceptive drains should be provided at the benches, which should be slightly inclined downwards towards the slope in order to maximize the efficiency of the interceptive drains. Erosion at the toe of the slope due to wave action may be detrimental to the safety of the slope. Thus erosion protection in the form of a geotextile, non-woven filter covered by a thin layer of coarse gravel or shattered rock is recommended.

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3. Chan, H.T. 1986 "Nanticoke GS - Stability of Proposed Ash Pile". Memorandum 2, File 843.12 Nan., Civil Research Department, Ontario Hydro.

4. Lau, K.C. and Chan, H.T. 1989. "The Study of a Water Table Within a Fly Ash Mound at Nanticoke". Ontario Hydro Research Division Report No 89-39-K.

5. Chan, H.T. 1985. "Stability Study of Nanticoke Ash Dykes". Ontario Hydro Research Division Report No. 85-303-K.

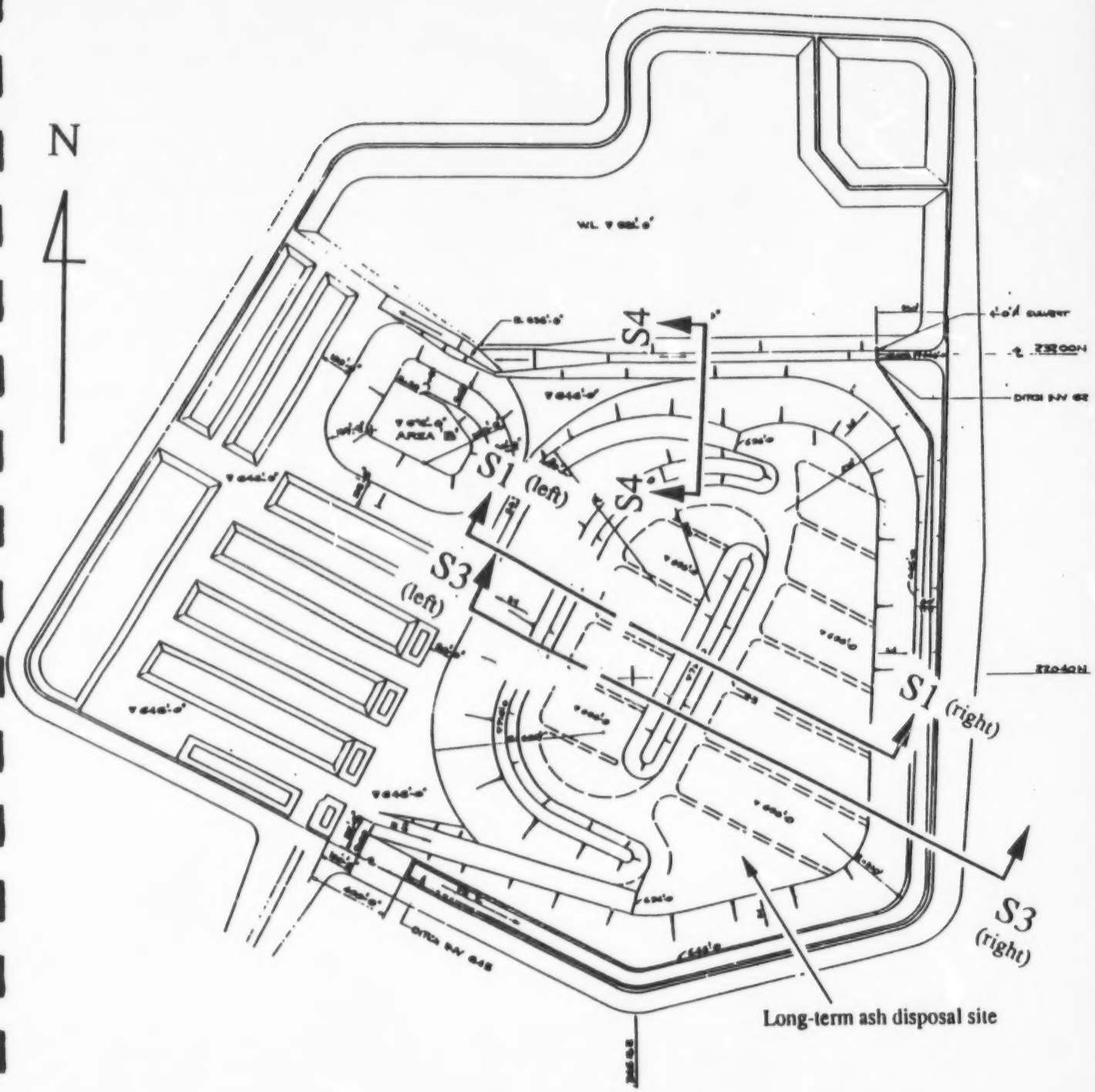

Figure 1 Locations of selected critical slope sections at the proposed fly ash mound. (modified from Civil Design drawing No. NA59.SK84, some sections shown in the original drawing were not critical and hence were not analysed for their stability)

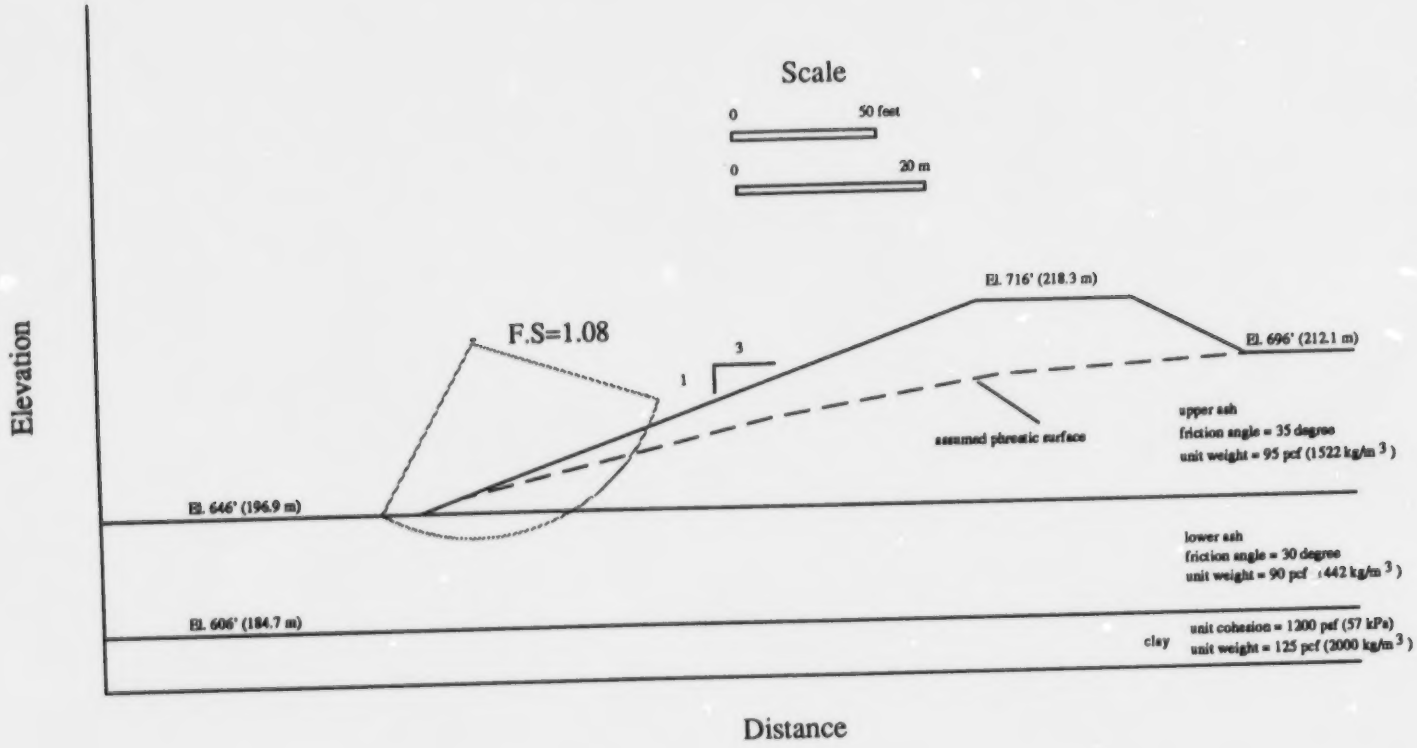

Figure 2 Section S1 "left side" - Initial analysis.

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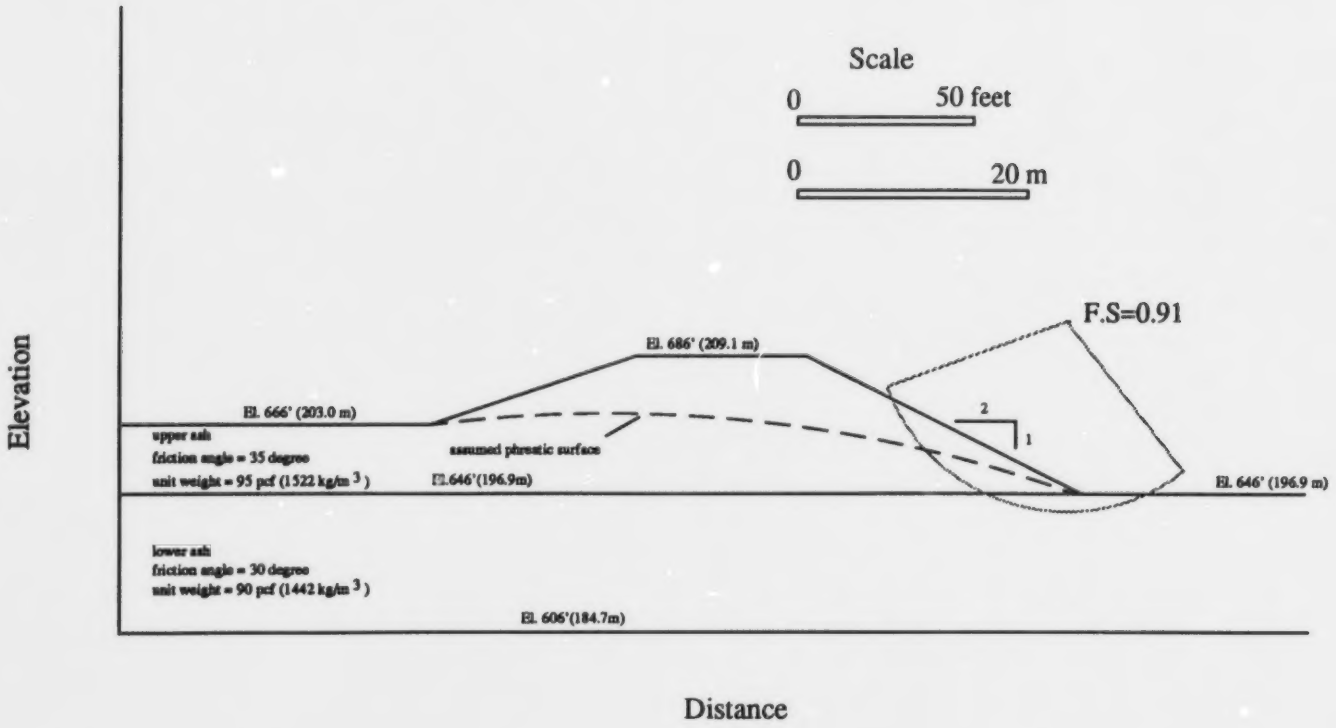

Figure 3 Section S1 "right side" (short-term, during construction) - Initial analysis.

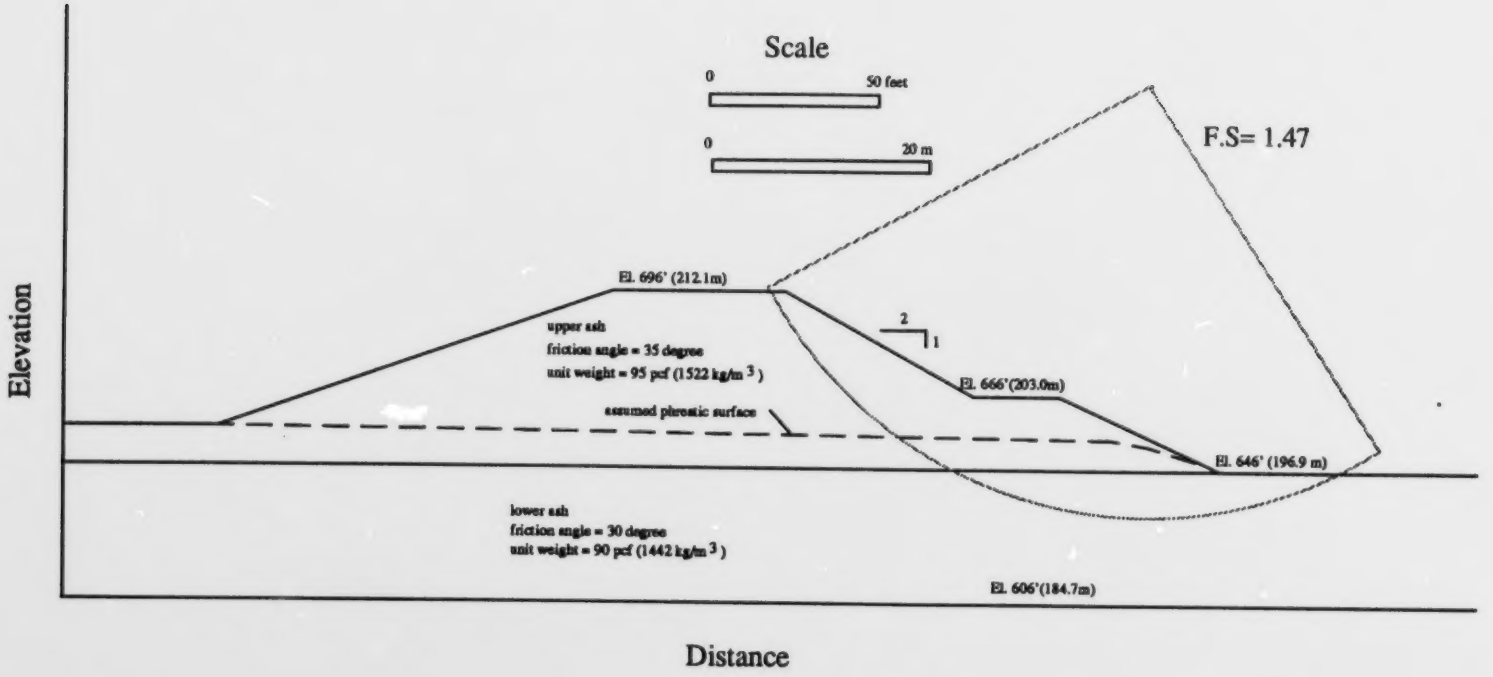

Figure 4 Section S3 (short-term, during construction) - Initial analysis.

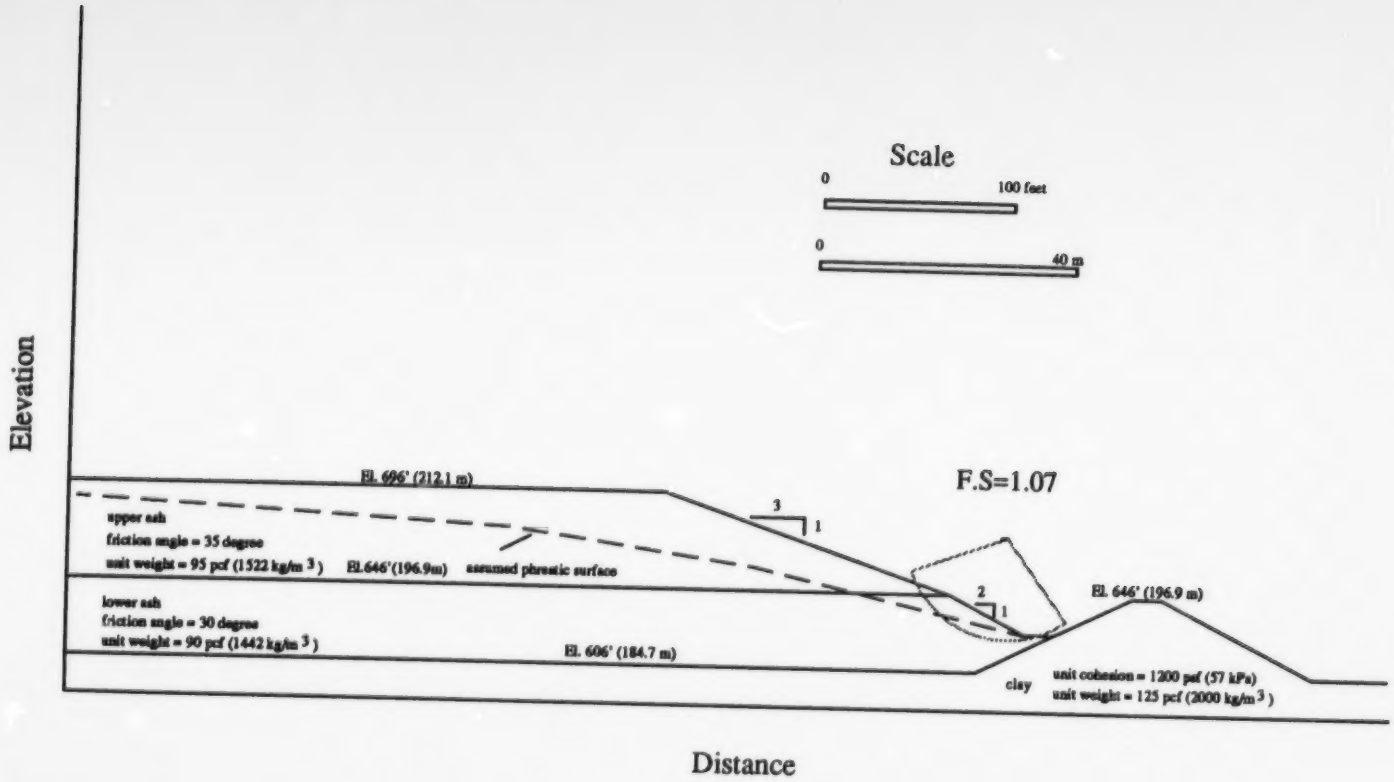

Figure 5 Section S3 - Slope profile at the end of construction (long-term condition).

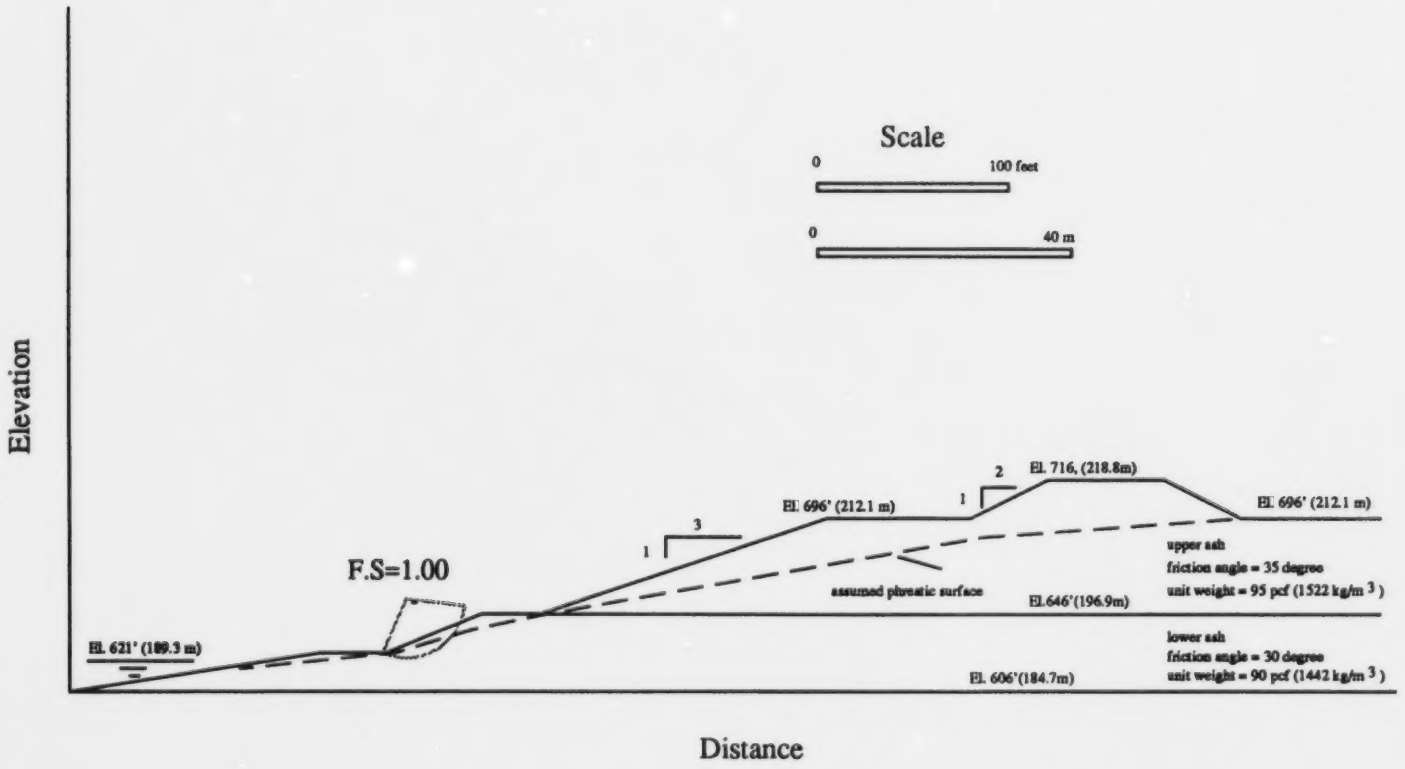

Figure 6 Section S4 - Initial analysis.

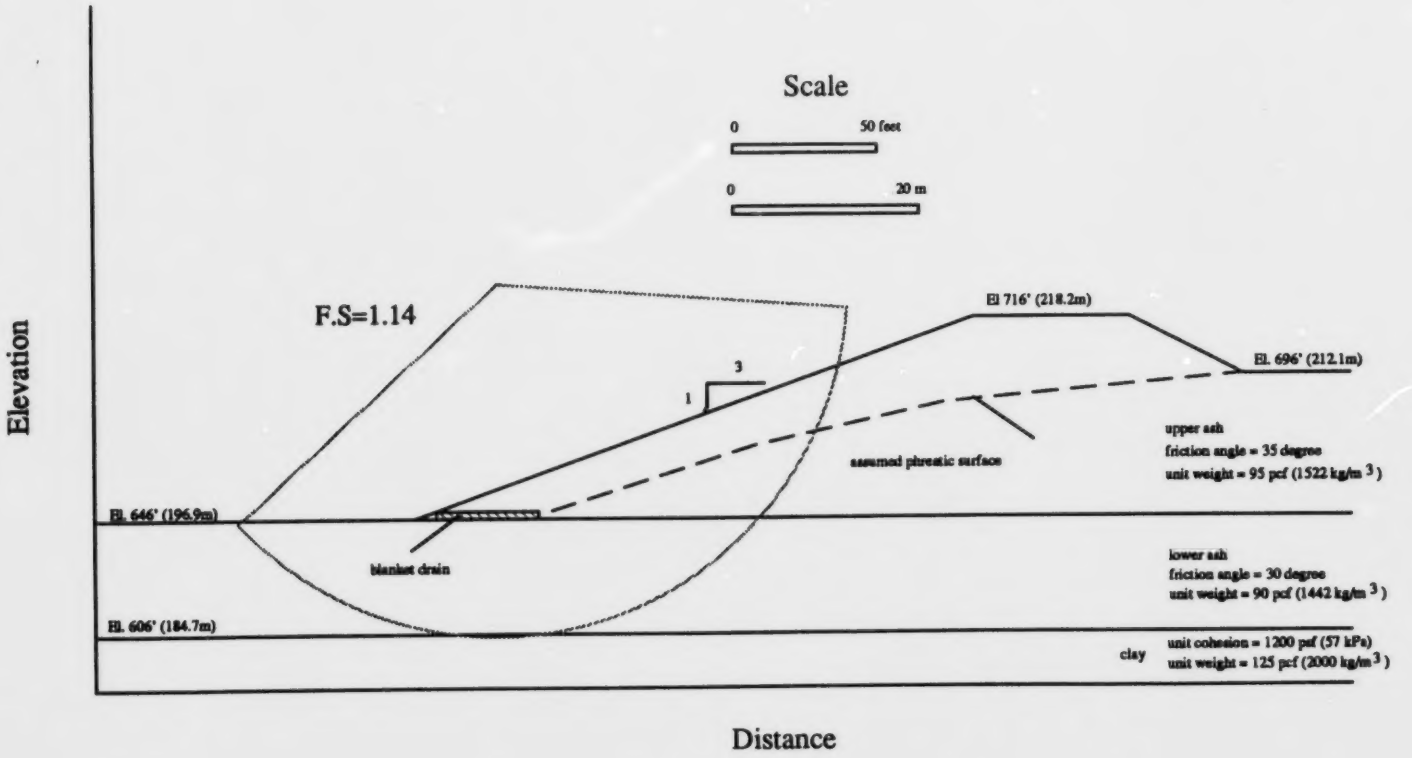

Figure 7 Slope stability improvement by blanket drain - Section S1 "left side".

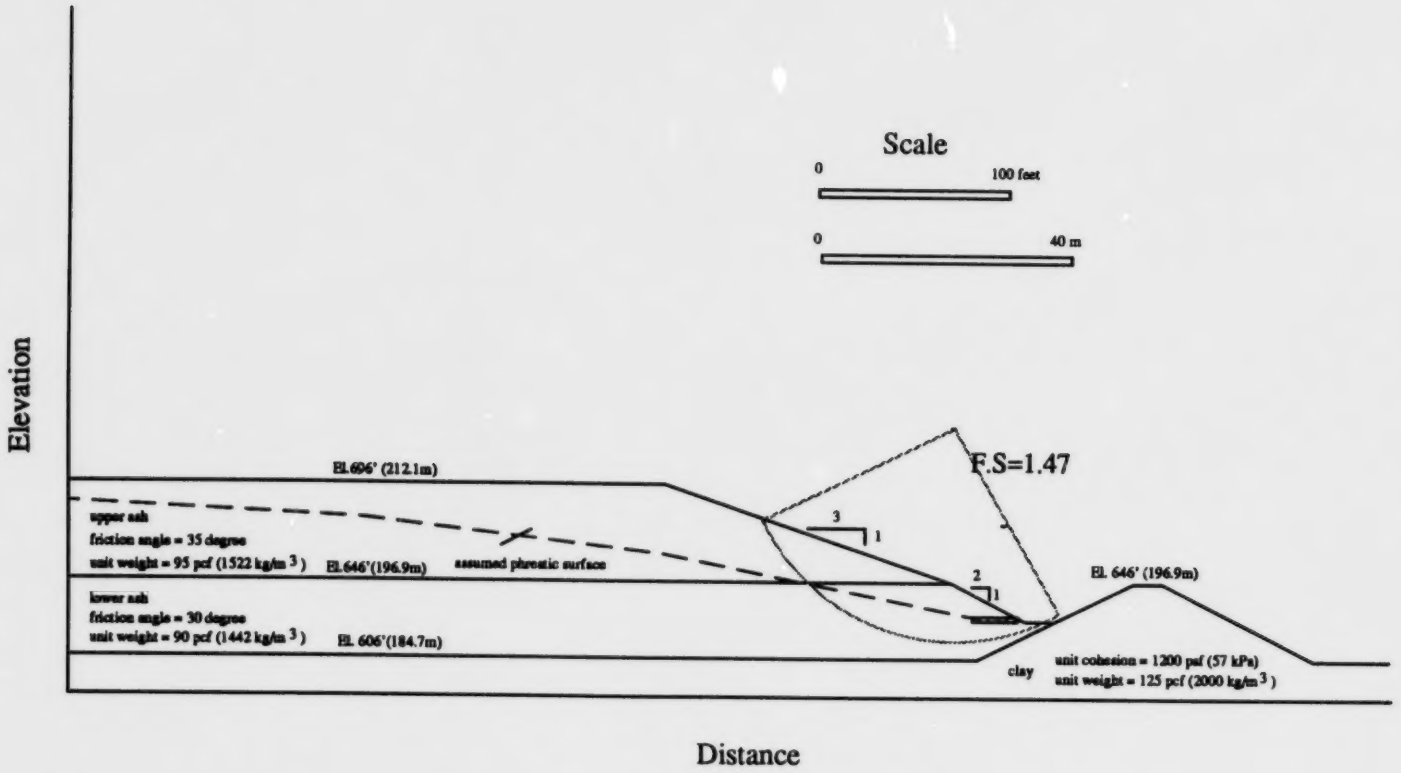

Figure 8 Slope stability improvement by blanket drain - Section S3.

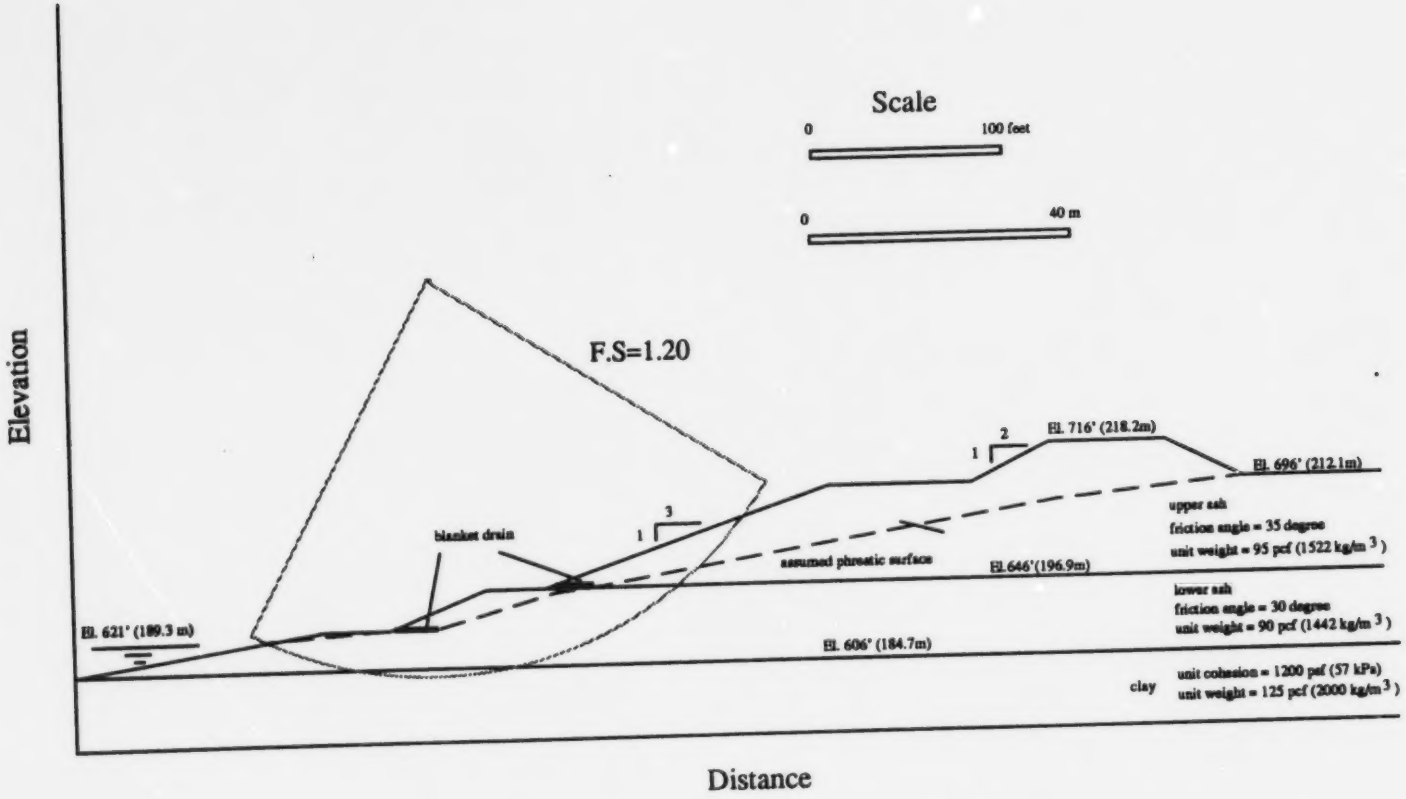

Figure 9 Slope stability improvement by blanket drain - Section S4.

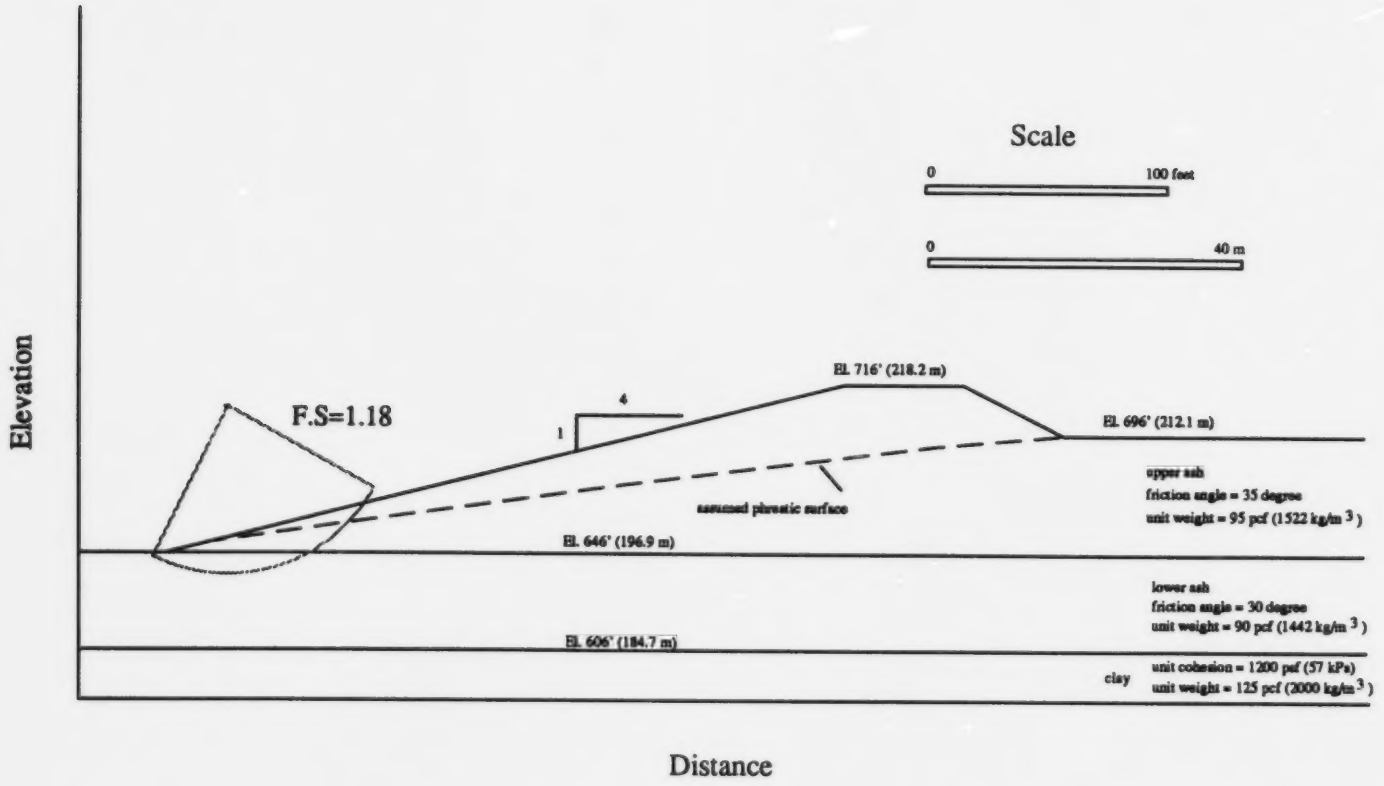

Figure 10 Slope stability improvement by slope flattening - Section S1 "left side".

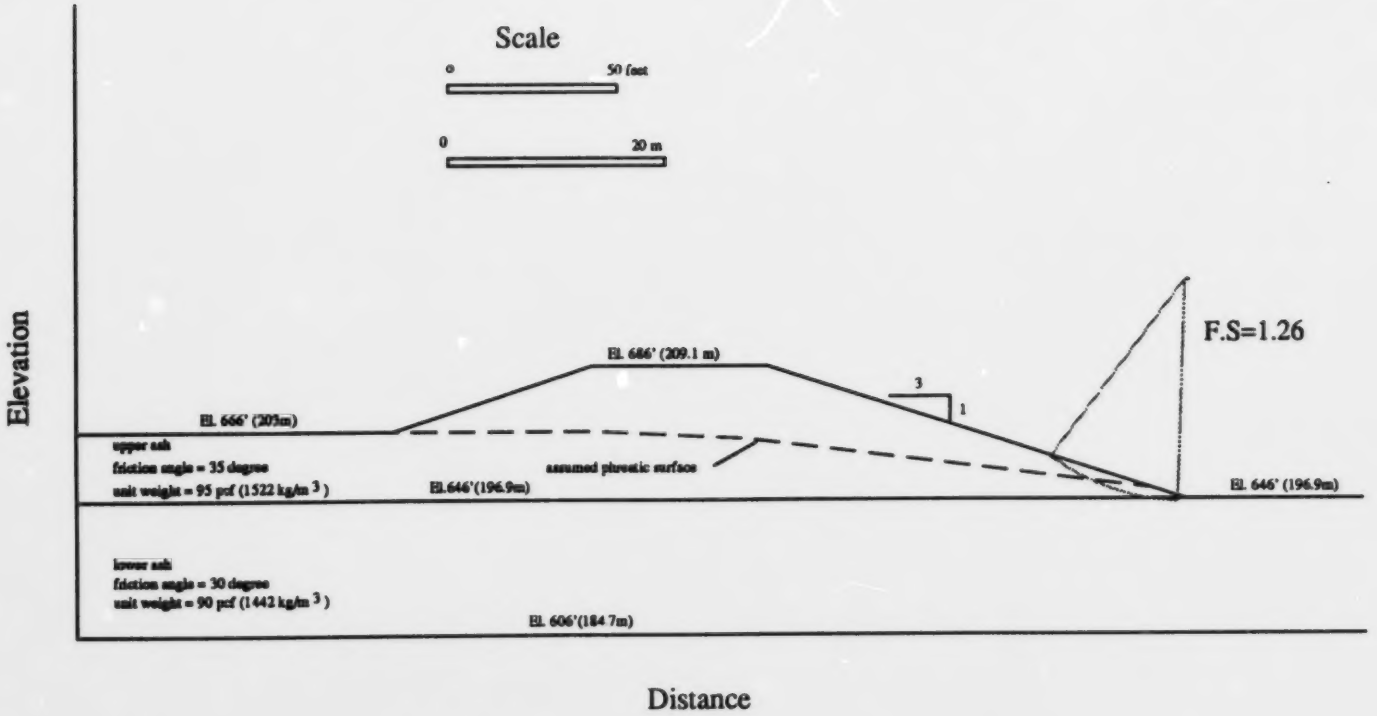

Figure 11 Slope stability improvement by slope flattening - Section S1 "right side".

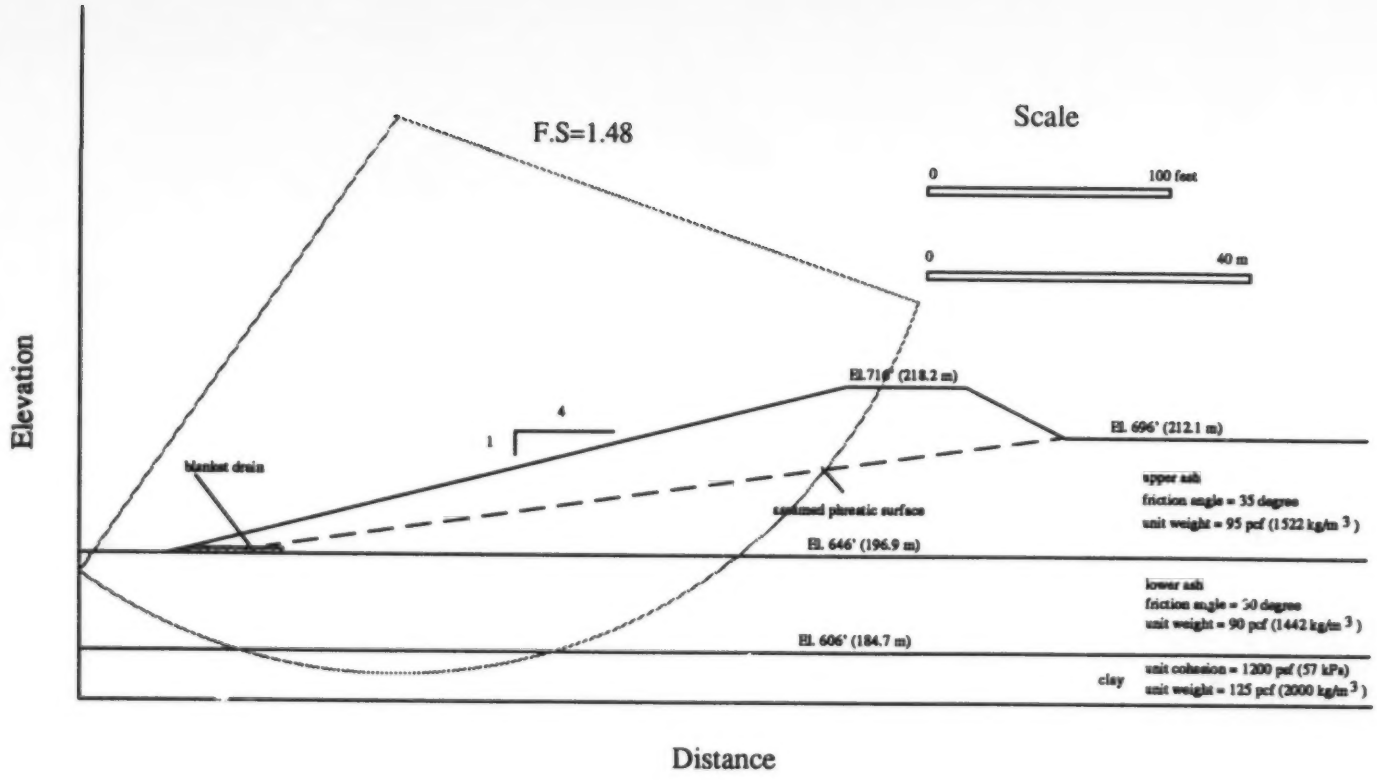

Figure 12 Slope stability improvement by both slope flattening and blanket drain - Section S1 "left side".

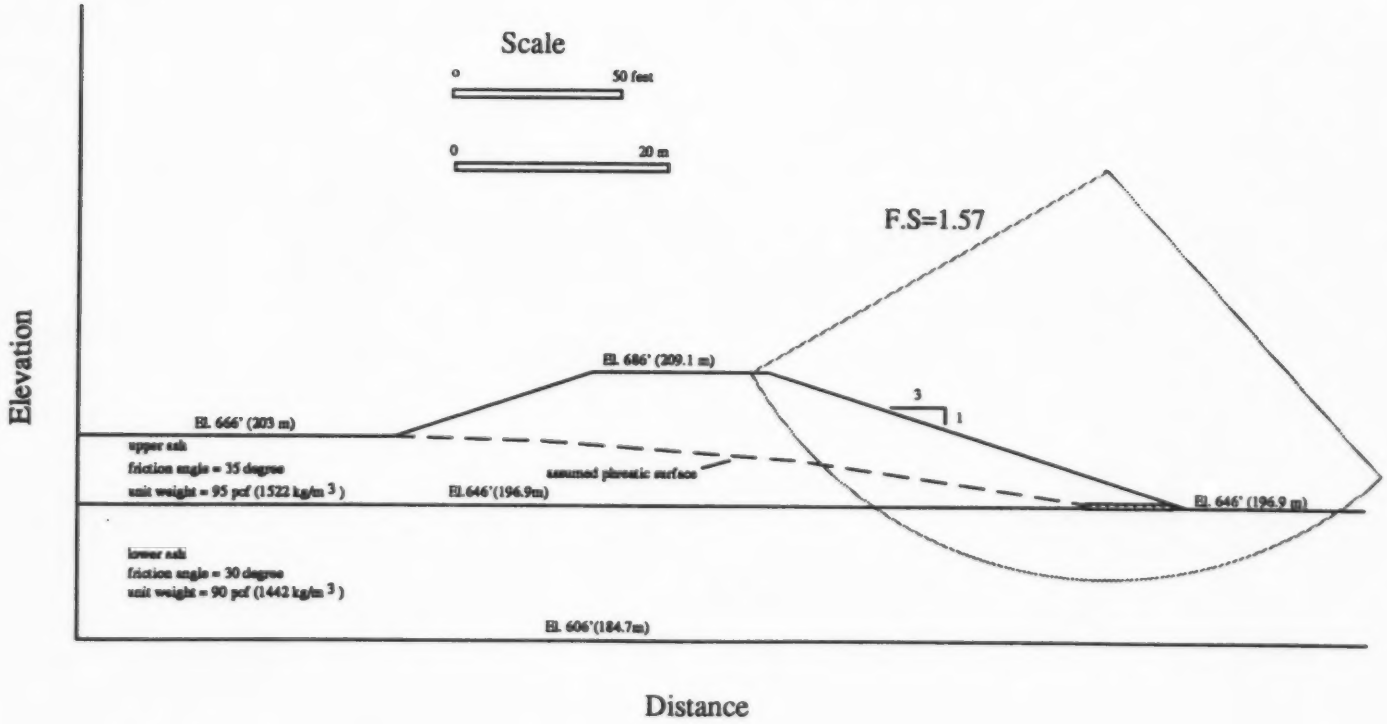

Figure 13 Slope stability improvement by both slope flattening and blanket drain - Section S1 "right side".

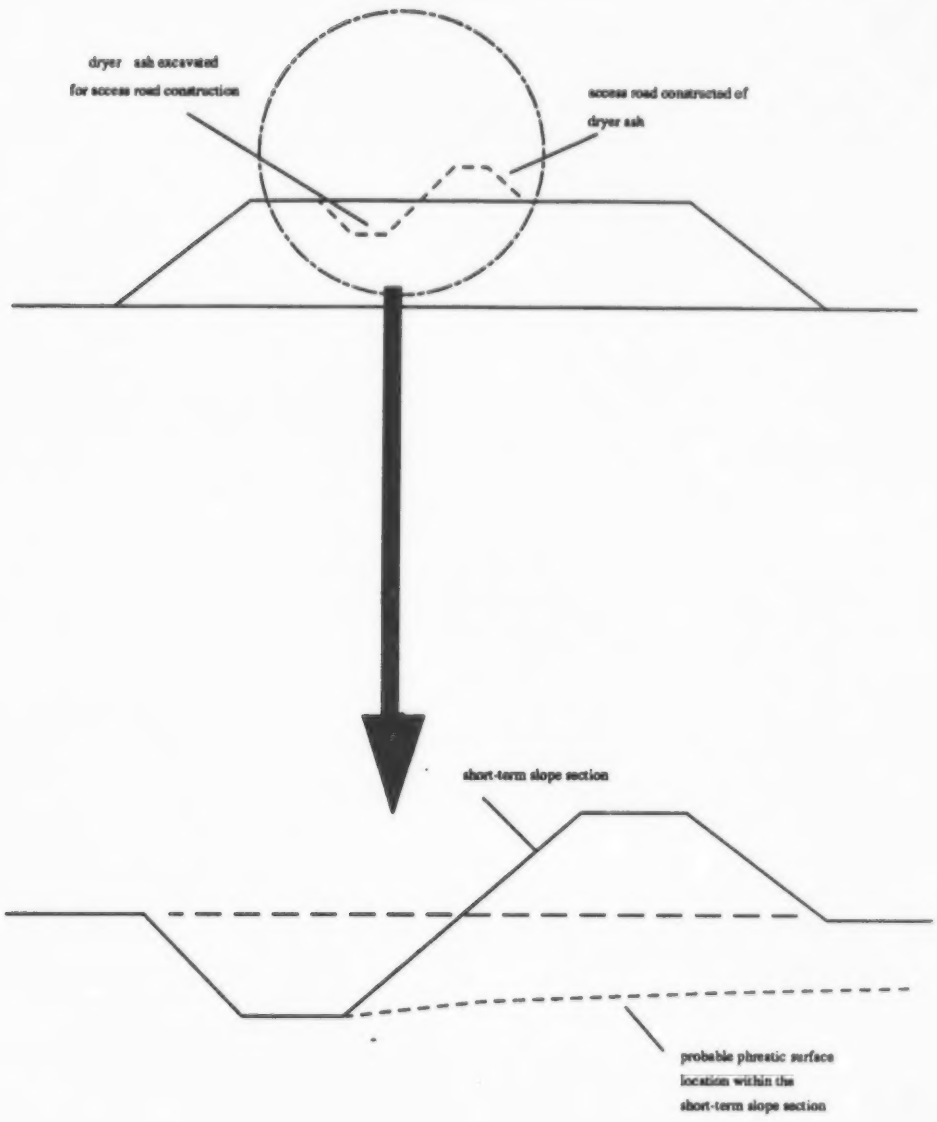

Figure 14 The probable phreatic surface location within a short-term slope section.

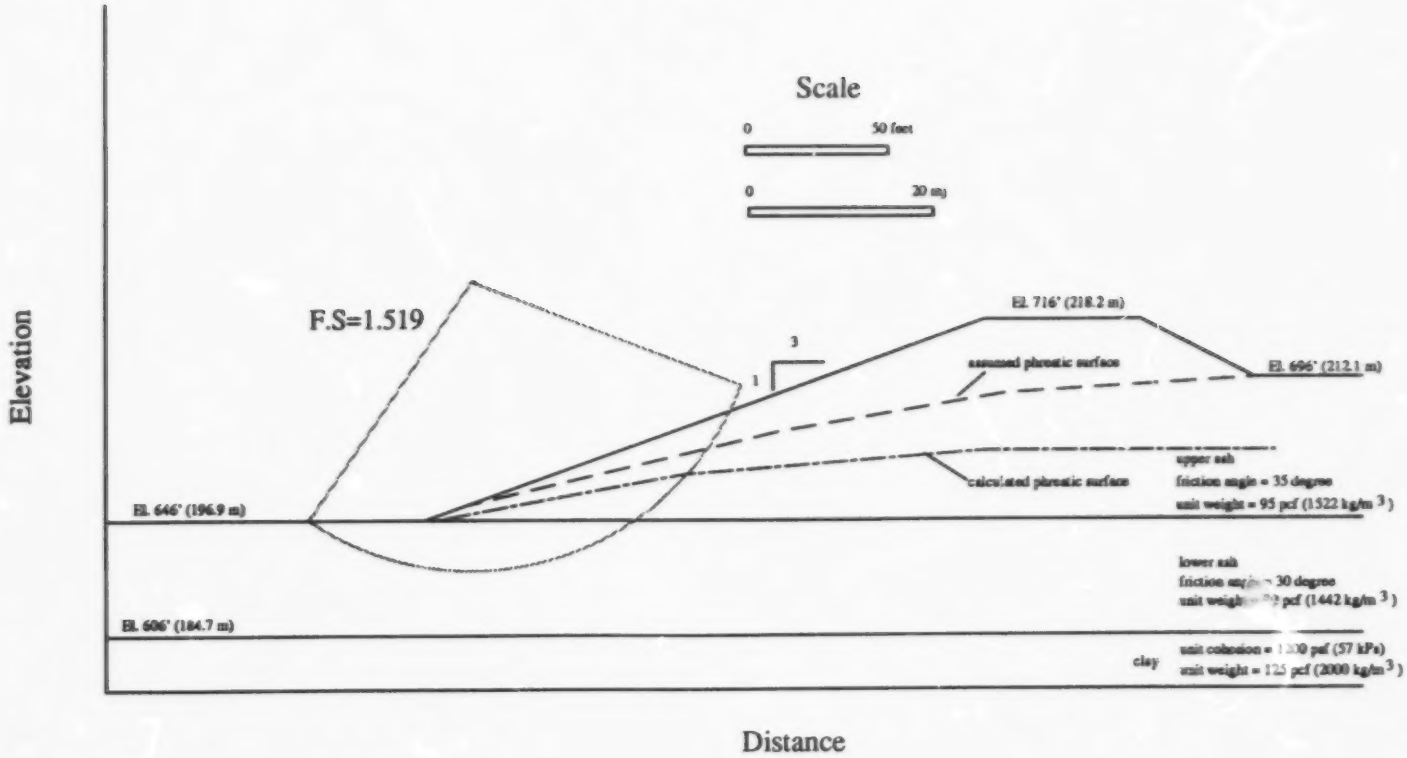

Figure 15 Stability of slope with calculated phreatic surface
- Section S1 "left side".

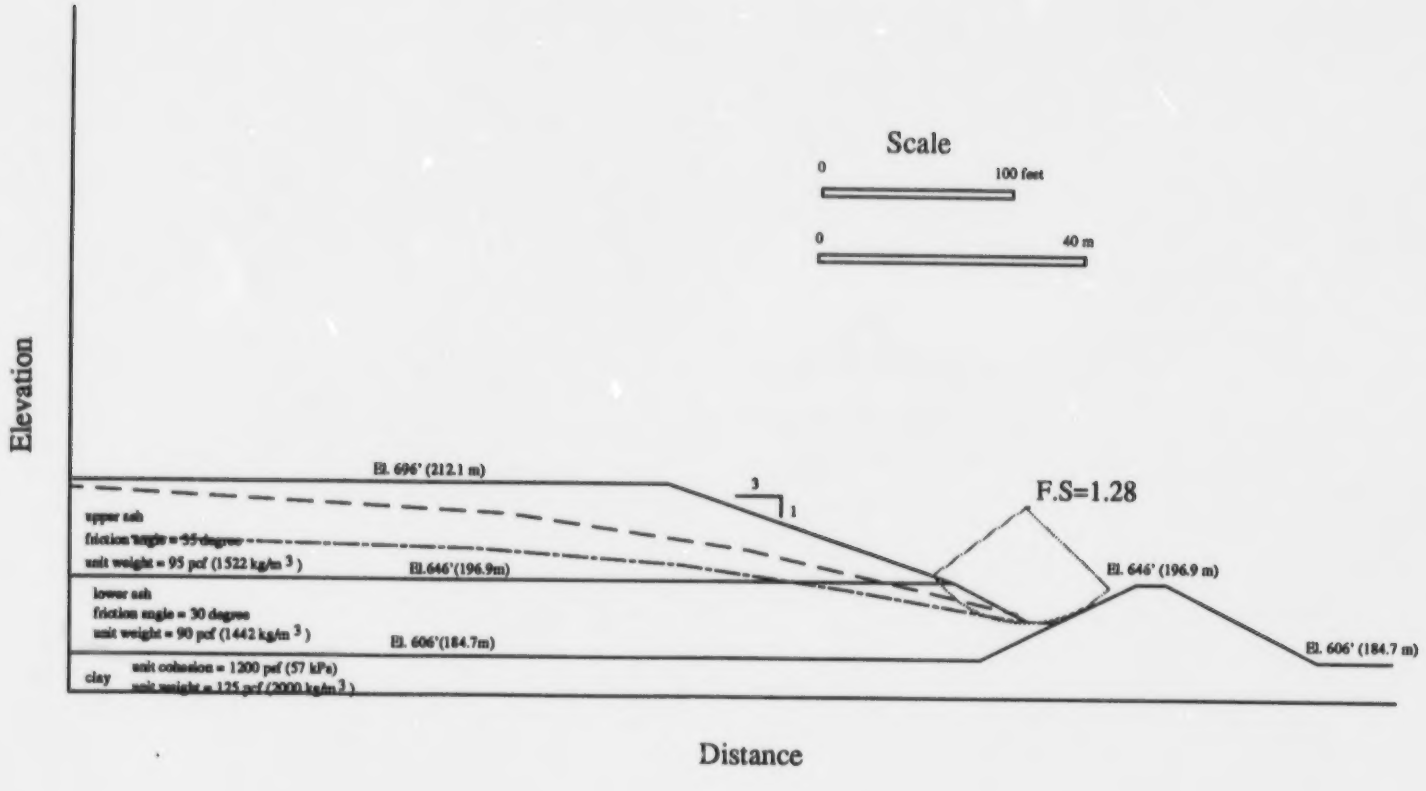

Figure 16 Stability of slope with calculated phreatic surface - Section S3.

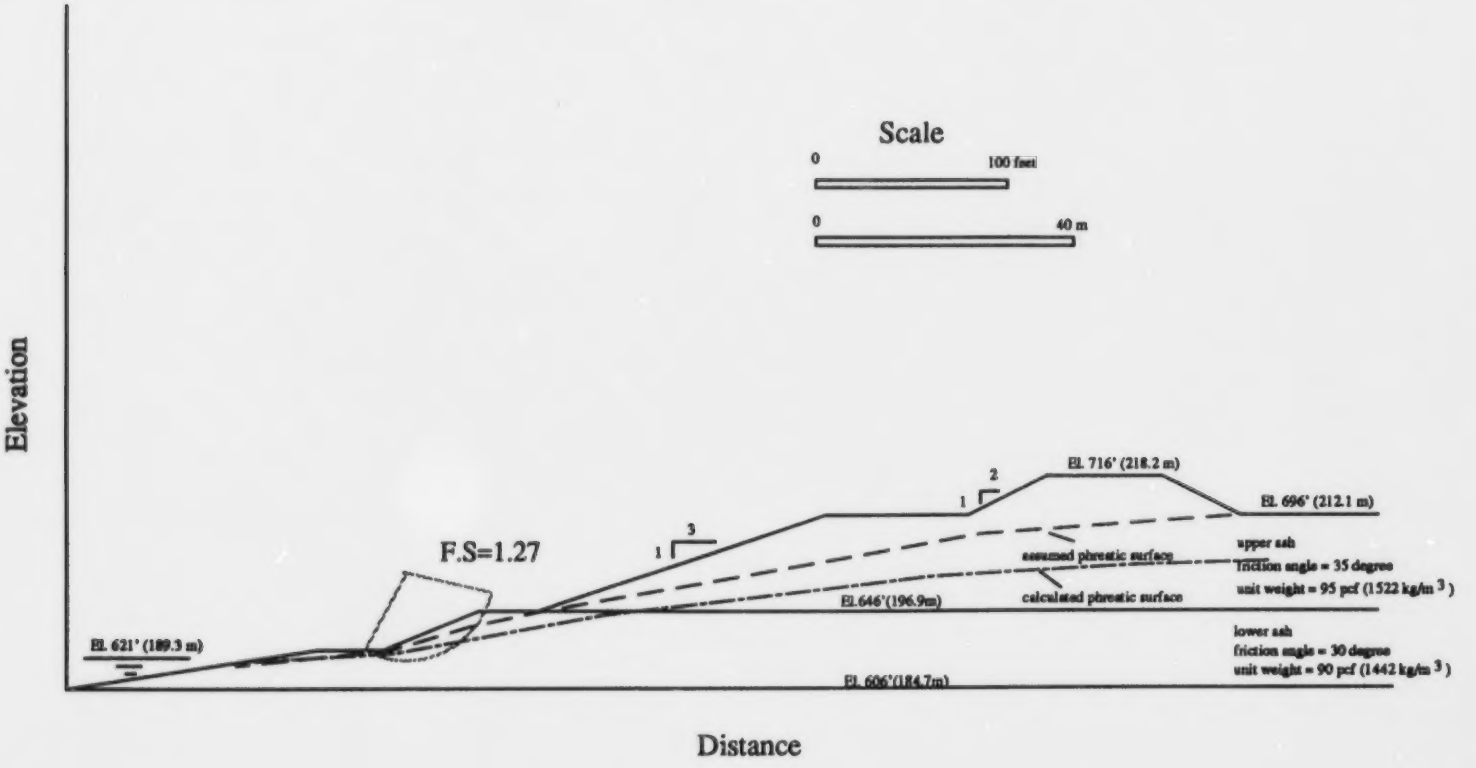

Figure 17 Stability of slope with calculated phreatic surface - Section S4.

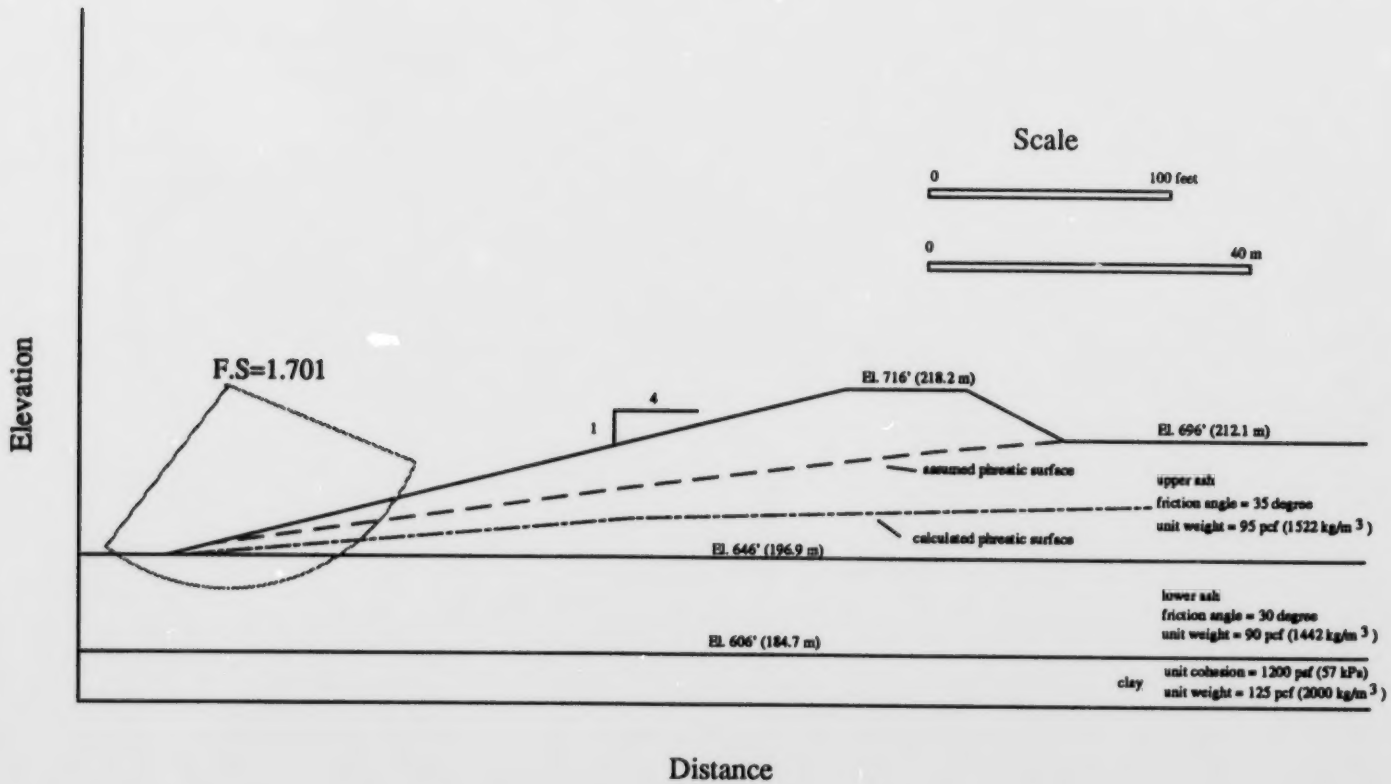

Figure 18 Stability of slope with calculated phreatic surface - Section S2.

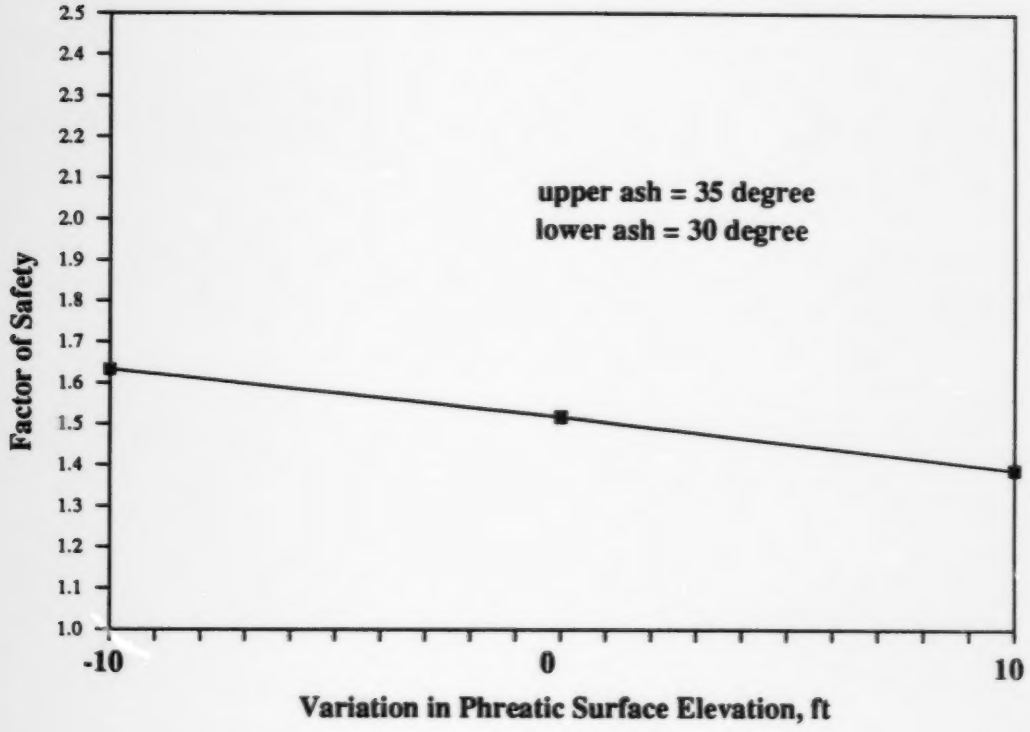

Figure 19 Effect of phreatic surface elevation on the stability of the slope - section S1 "left side".

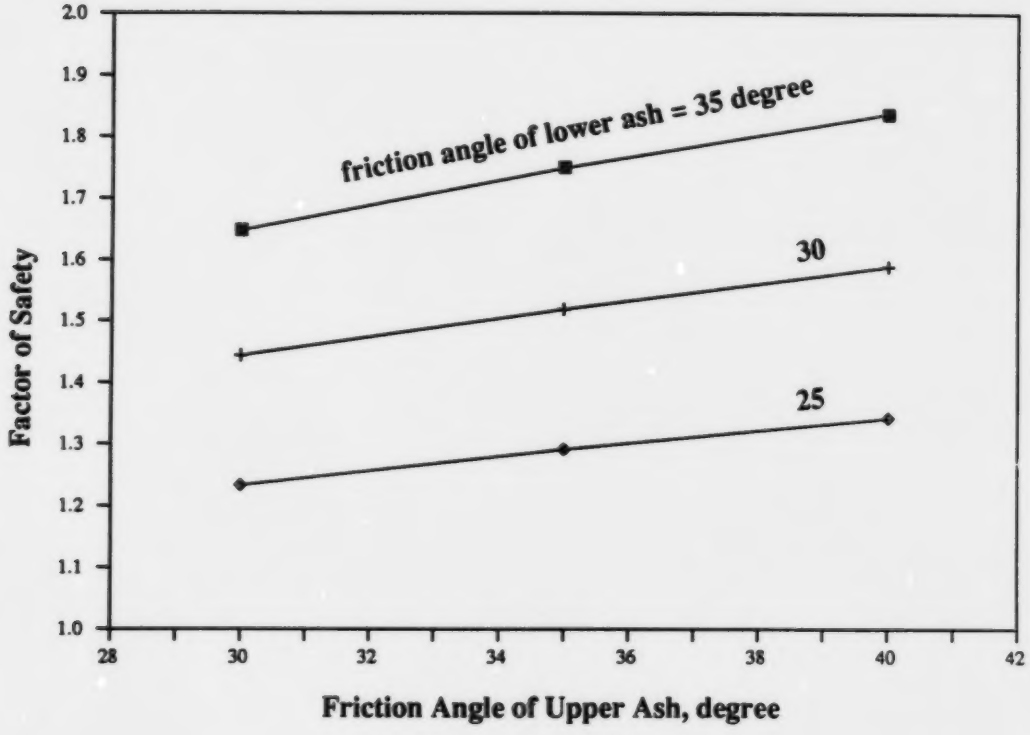

Figure 20 Effect of variation in shear strength of the upper ash on the stability of the slope - section S1 "left side".

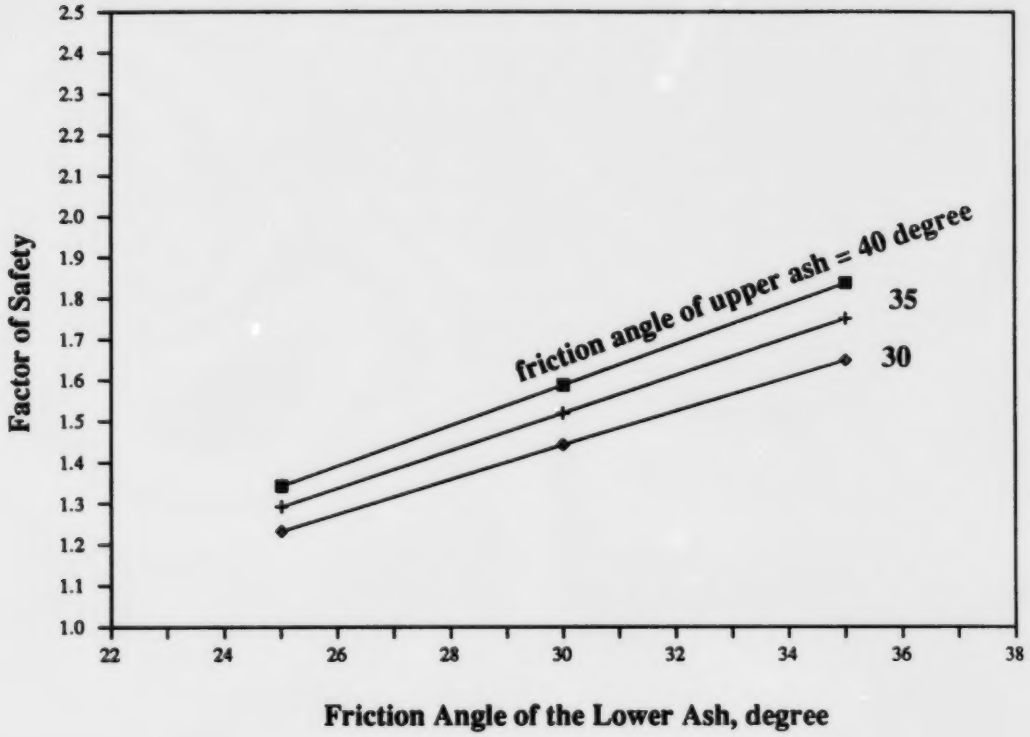

Figure 21 Effect of variation in shear strength of the lower ash on the stability of the slope - section S1 "left side".

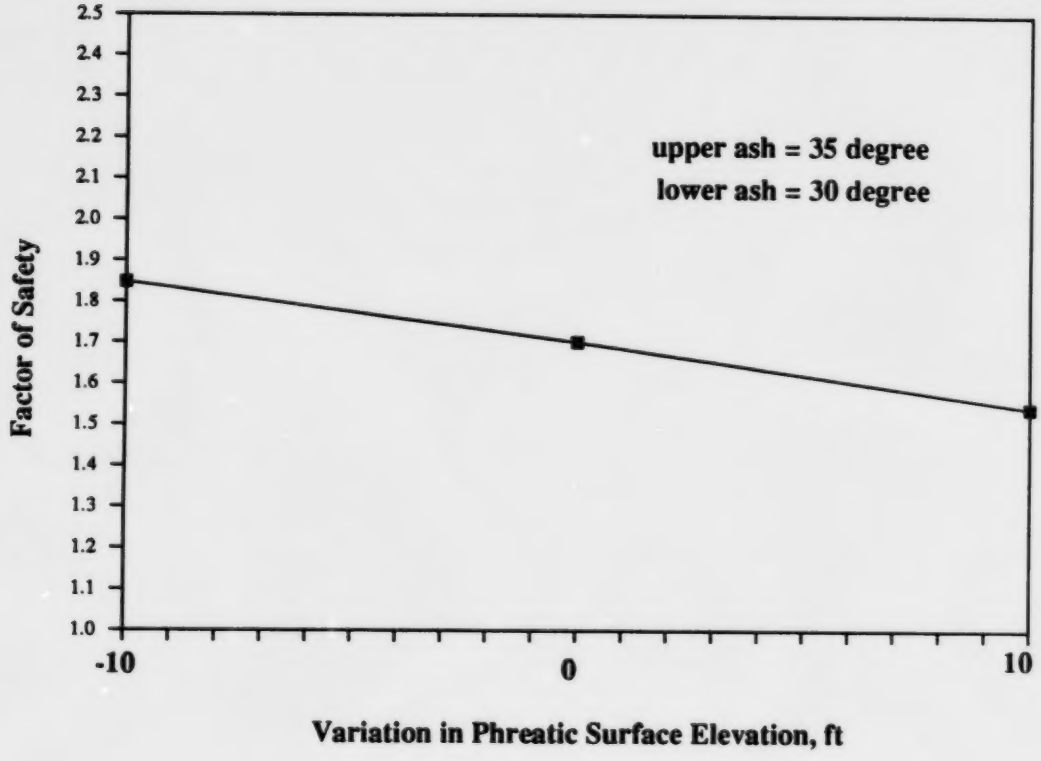

Figure 22 Effect of phreatic surface elevation on the stability of the slope - section S2

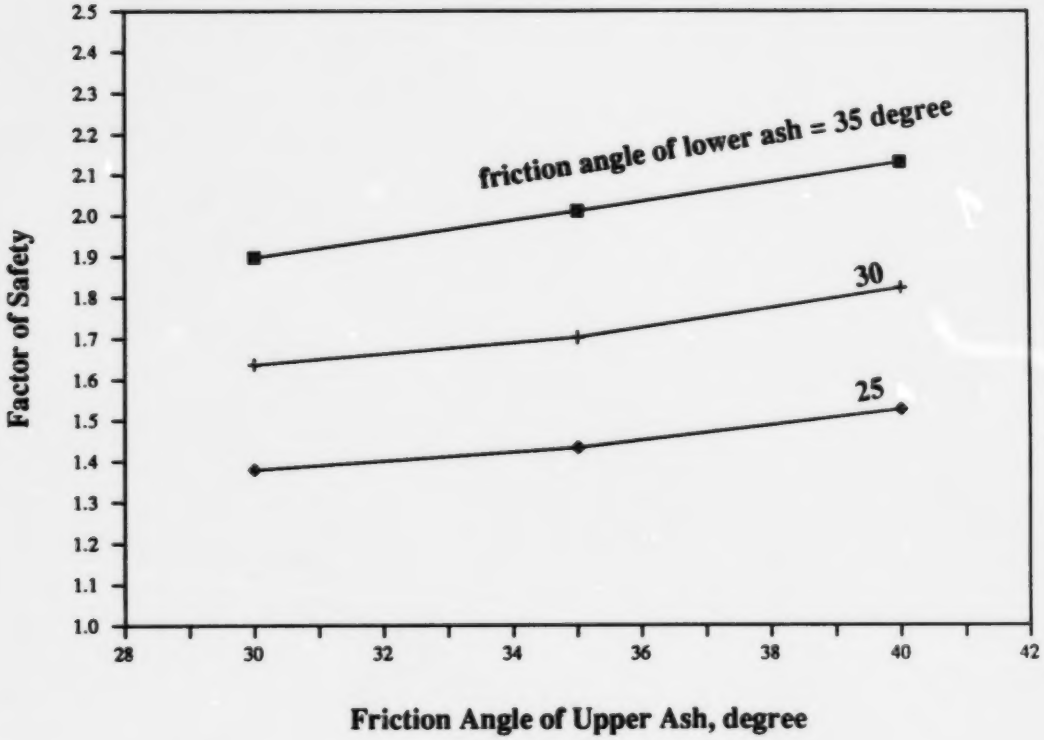

Figure 23 Effect of variation in shear strength of the upper ash on the stability of the slope - section S2.

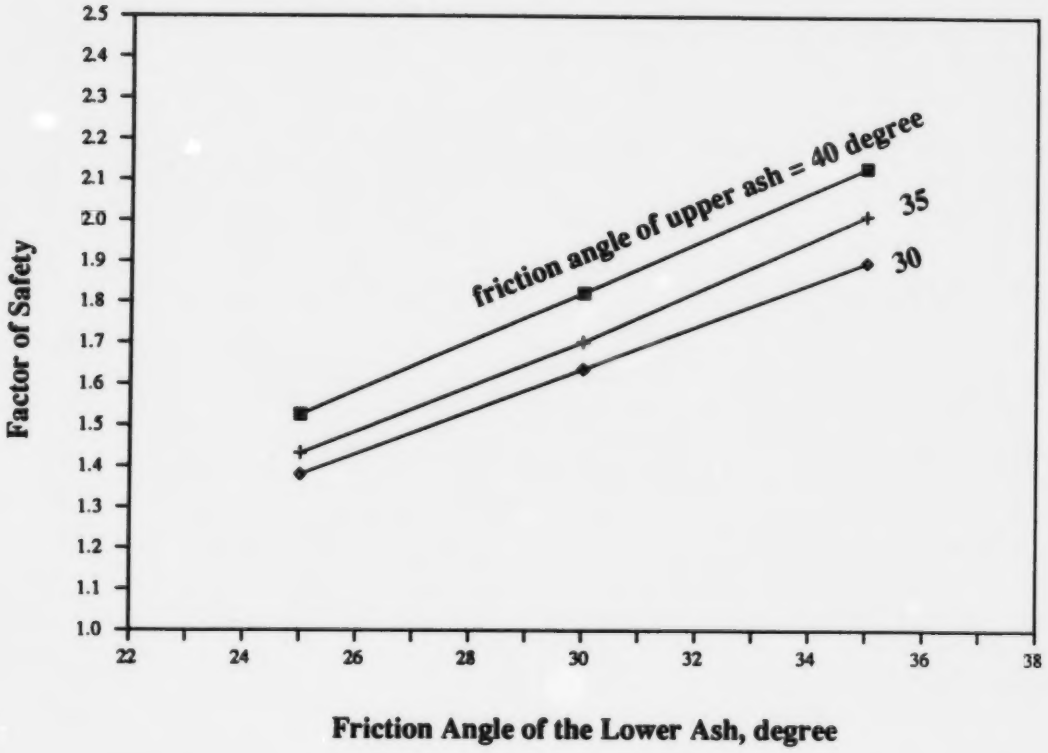

Figure 24 Effect of variation in shear strength of the lower ash on the stability of the slope - section S2

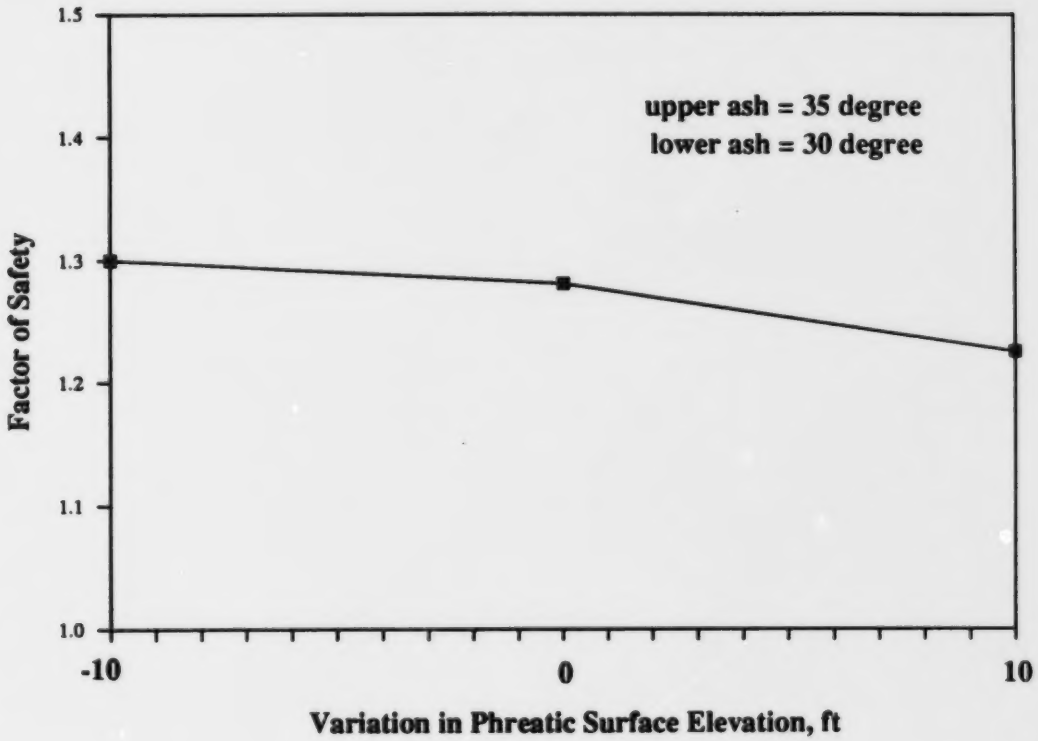

Figure 25 Effect of phreatic surface elevation on the stability of the slope - section S3.

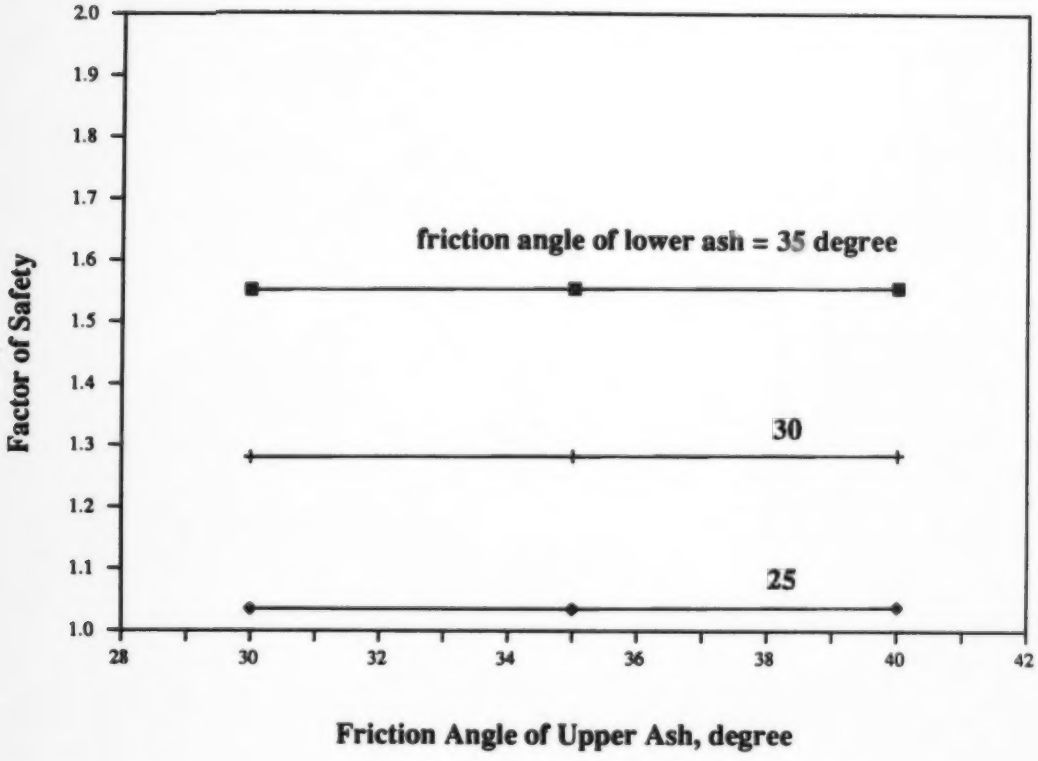

Figure 26 Effect of variation in shear strength of the upper ash on the stability of the slope - section S3.

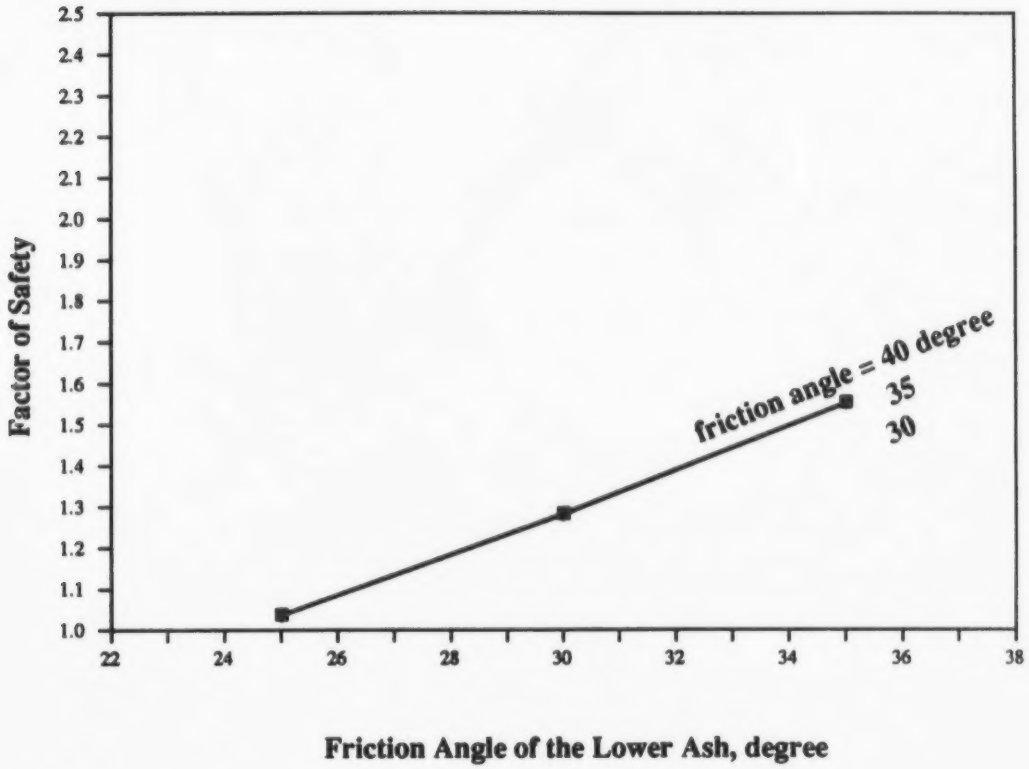

Figure 27 Effect of variation in shear strength of the lower ash on the stability of the slope - section S3.

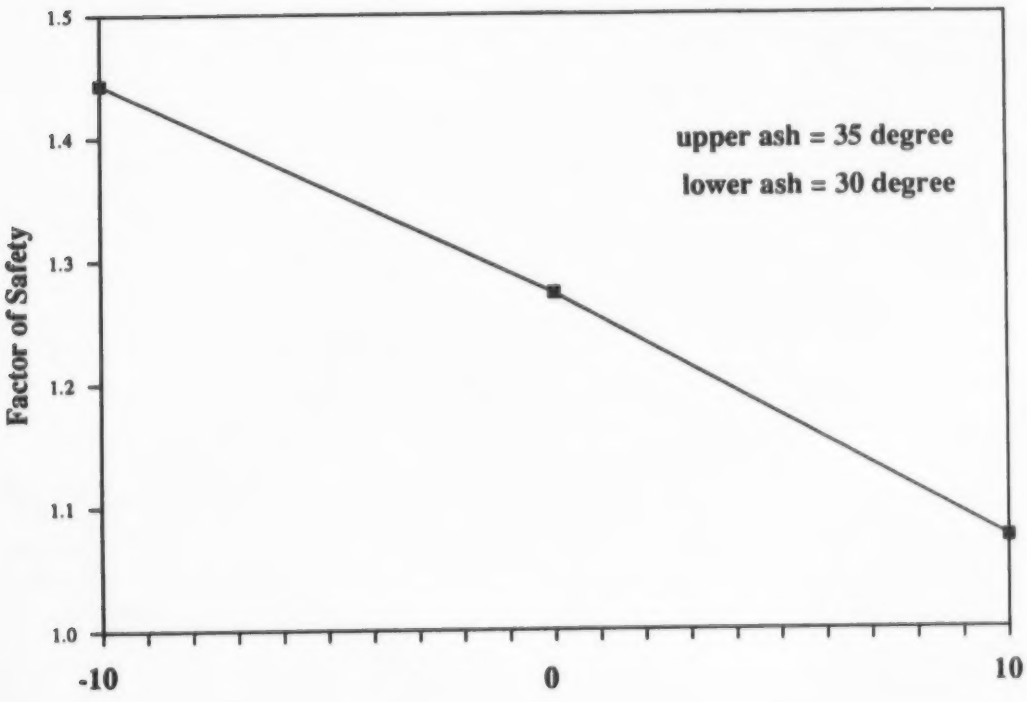

Figure 28 Effect of phreatic surface elevation on the stability of the slope - section S4.

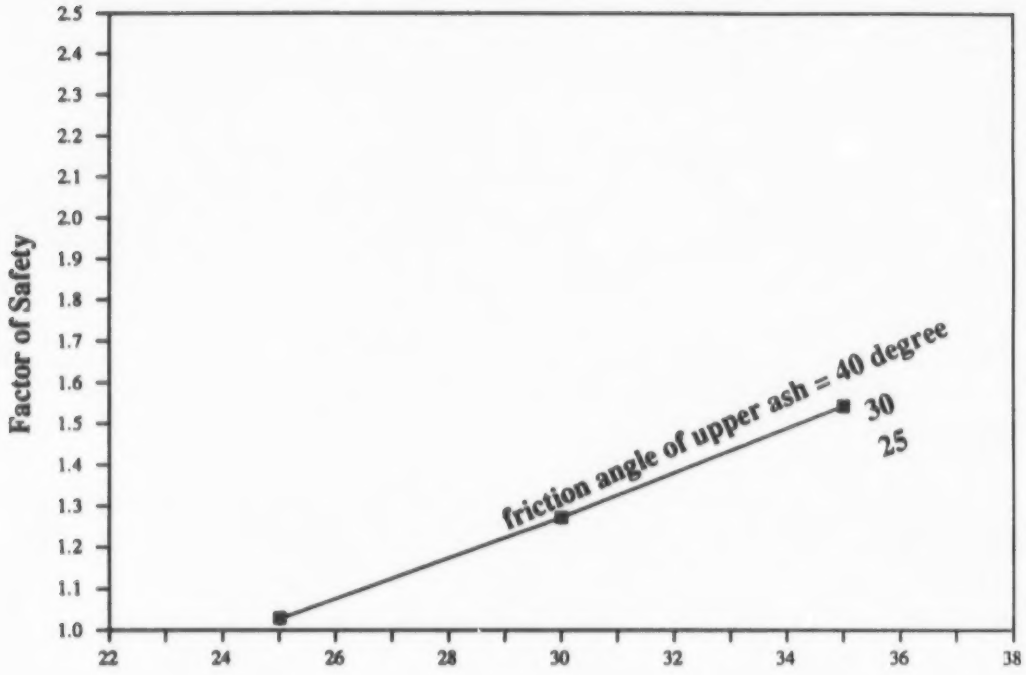

Figure 29 Effect of variation in shear strength of the lower ash on the stability of the slope - section S4.

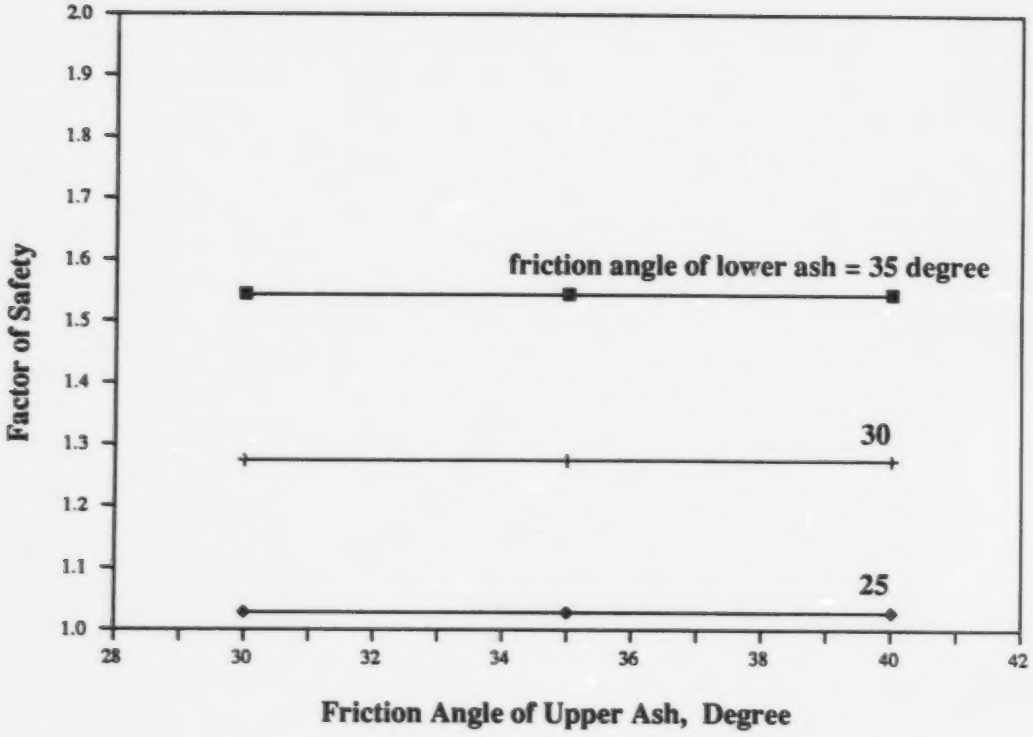

Figure 30 Effect of variation in shear strength of the upper ash on the stability of the slope - section S4

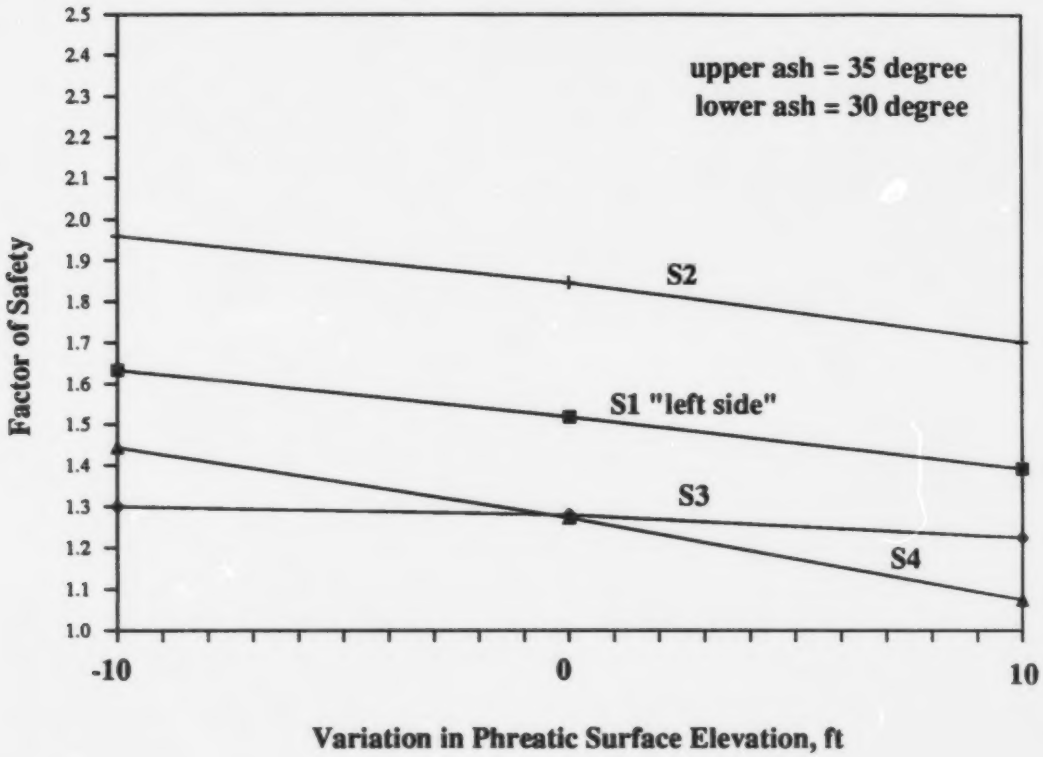

Figure 31 Effect of phreatic surface elevation on the stability of the slopes.

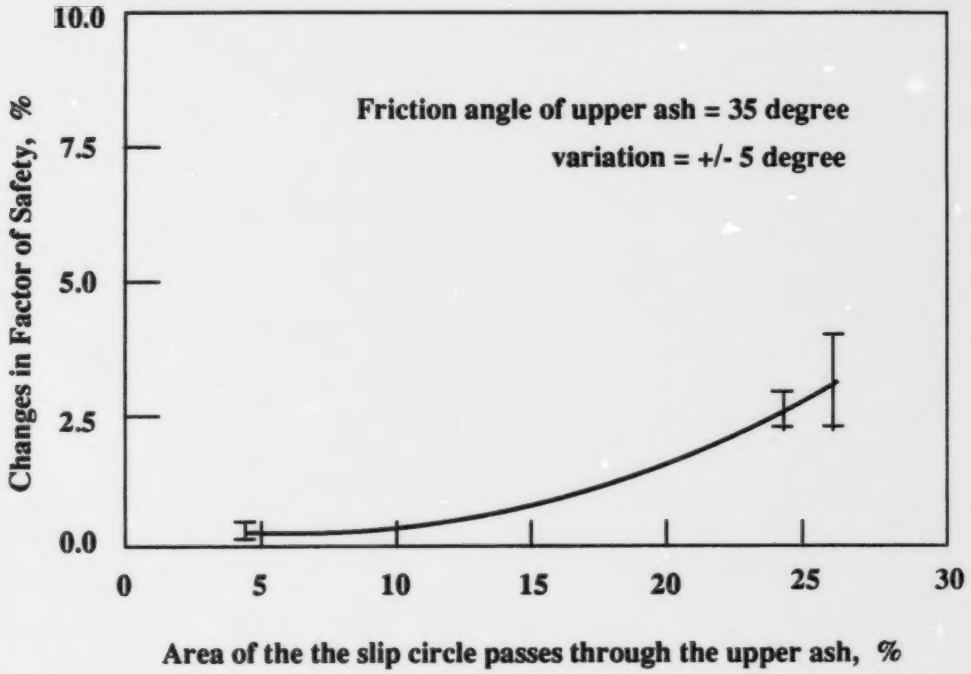

Figure 32 Percentage changes in factor of safety caused by change in shear strength of the upper ash versus the area of slip surface passes through the upper ash.

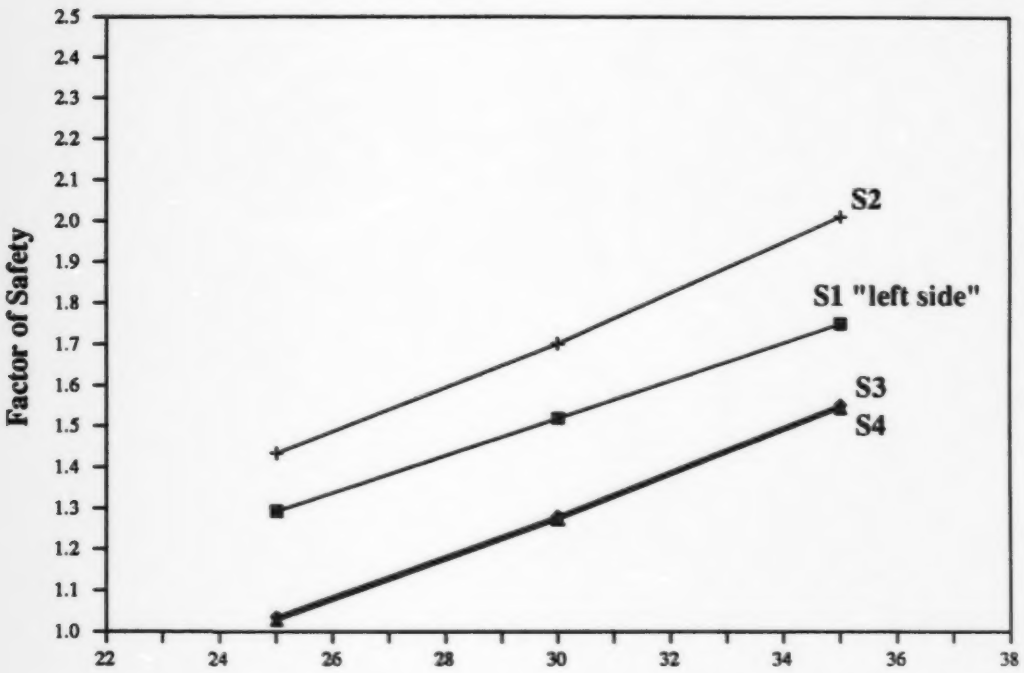

Figure 33 Effect of variation in shear strength on the stability of the slopes.

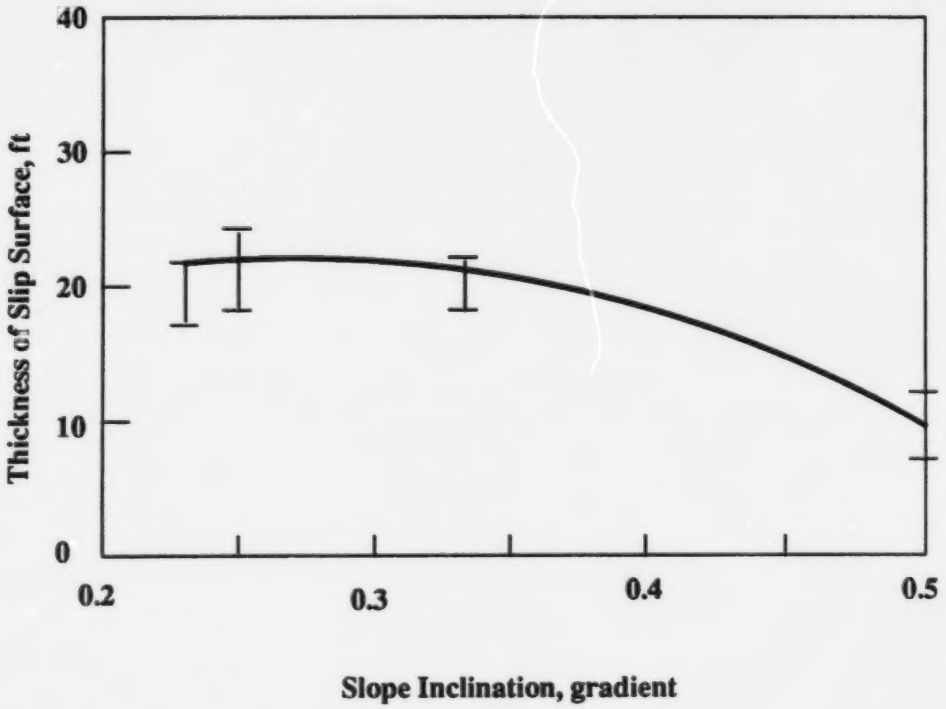

Figure 34 Slope inclination versus the thickness of the slide.

APPENDIX A

Determination of the Location of the Phreatic Surface

The procedure for calculating the location of the phreatic surface is described in Ontario Hydro Research Report No 89-39-K* and is not repeated here. The following is a numerical example:

The average hydraulic conductivity of the ash determined from the field is $5x10^{-7}$ m/s and the pore air ratio, n_a, of the ash determined from laboratory tests is 0.42/4/. Assuming that the ash mound has an expected operating life of 30 years, the time factor, T, is equal to;

$$T=(30x360x5x10^{-7})/0.42= 0.013 \text{ day m/s}$$

The rate of infiltration into the mound was estimated to be $1.77x10^{-8}$ m/s. Thus the infiltration ratio is equal to/4/;

$$I/k = 1.77x10^{-8}/5x10^{-7} = 0.035$$

From Figure A-1, the phreatic surface at the end of construction is 46 ft (14m) above the base of the mound. The water level of the primary lagoon at the site is at 621 ft (189.3m). Thus the elevation of the phreatic surface at the end of construction is at 667 ft (203.3m).

*Lau, K.C. and Chan, H.T. 1989 "The Study of a Water Table Within a Fly Ash Mound at Nanticoke". Ontario Hydro Research Division Report No 89-39-K.

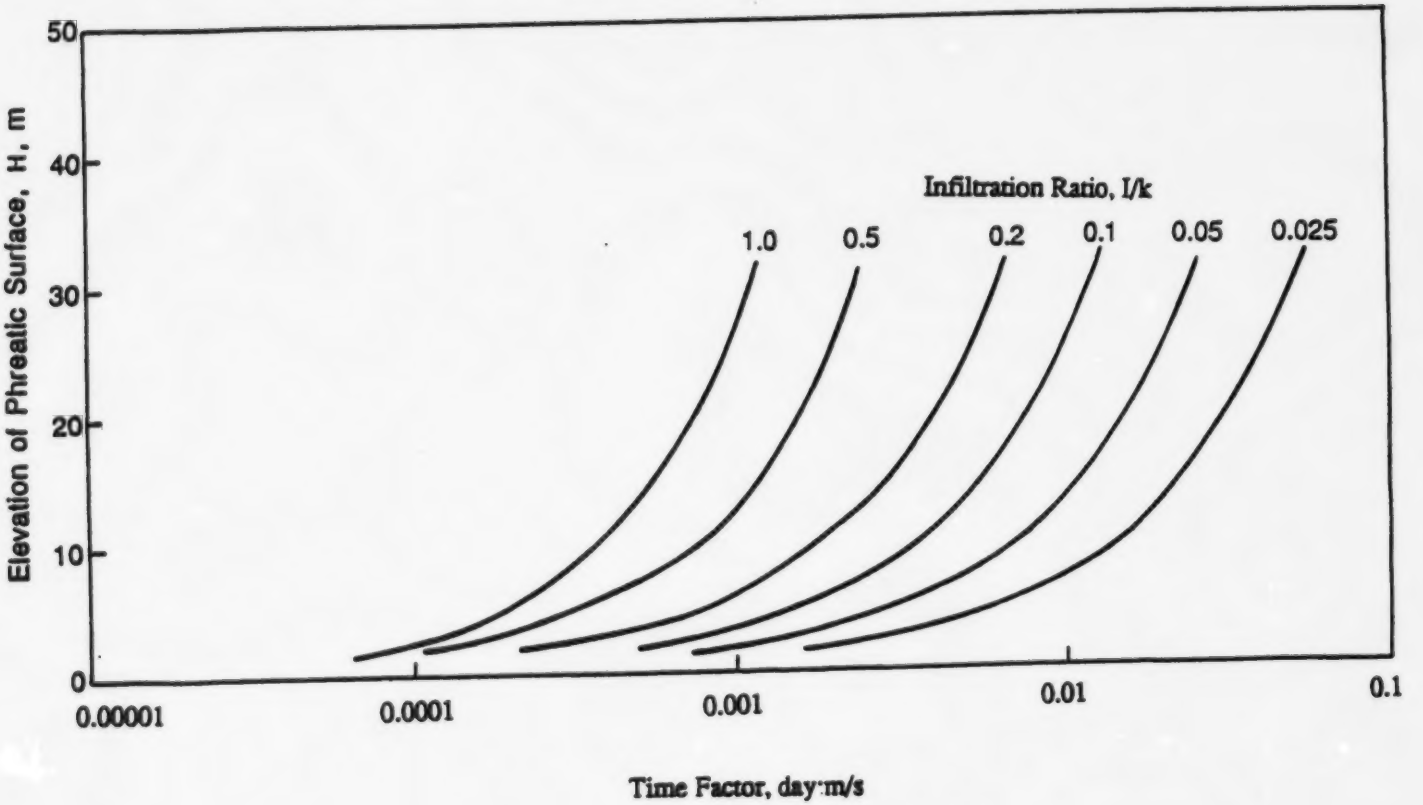

Figure A-1 Phreatic surface elevation versus time factor, 2-D planar flow - 3:1 slope.

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